



UNION OF SOUTH AFRICA

DEPARTMENT OF COMMERCE AND INDUSTRIES

DIVISION OF FISHERIES

INVESTIGATIONAL REPORT No. 16

THE SOUTH AFRICAN PILCHARD

(Sardinops ocellata)

THE TEMPERATURE, SALINITY AND INORGANIC PHOSPHATE
CONTENT OF THE SURFACE LAYER NEAR ST. HELENA BAY,

1950-52

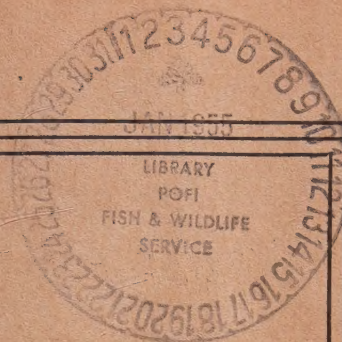
BY

A. J. CLOWES, D.Sc., A.R.C.S.

(Principal Professional Officer)

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I. SUMMARY.

An account is given of some of the hydrological factors in the environment of the South African pilchard, *Sardinops ocellata* (Pappe), off the west coast of the Union of South Africa.

The water layers present, winds, currents and upwelling in the area are discussed.

A comparison is made of the temperature, salinity and inorganic phosphate-content present in the surface of the sea and in the 0-50 metres layer in two commercial pilchard-catch years from September, 1950, to August, 1951 and from September, 1951, to August, 1952. The comparison is treated on a seasonal and a yearly basis. Discussion is made of differences shown in the two years under review, such differences being small on a yearly basis in the whole area investigated but are considered to be significant at certain positions notably off Lambert's Bay, along the southern base line west of Saldanha Bay, and in the south-west of the routine area.

The range of temperature, salinity and inorganic phosphate-content in the two years is discussed and in the light of existing knowledge, the seasons are given when maximum and minimum values of these factors occur.

2. INTRODUCTION.

With the arrival in Cape Town of the Division of Fisheries' new research ship R.S. "*Africana II*" from overseas early in 1950, a start was made on the investigation of the South African pilchard, *Sardinops ocellata* (Pappe). This investigational report deals with the hydrological environment of this fish.

The report is restricted mainly to a discussion of the temperature, salinity and inorganic phosphate content of the sea surface and the upper 50 metres of sea-water in a region which includes the area where commercial fishing for pilchards takes place off the west coast of the Union of South Africa. The scope of the report is severely handicapped by staff shortages which have prevented, for instance, any attempt to treat the data hydrodynamically. More important still, wind data from the Union Weather Bureau have not been incorporated in this report due to lack of staff at the Division of Fisheries.

The South African pilchard is found at numerous places around the coasts of the Union of South Africa but, only on the West coast in the St. Helena

Bay area, is it present in the water near the coast for a long enough period to make commercial fishing an economic project. Thus every year in June, huge shoals of pilchards arrive off the coast of Natal providing, for a few weeks, sport for anglers who catch the larger fish which prey on the pilchard shoals. It is unlikely that these immense numbers of pilchards off the Natal coast can ever be utilized significantly for commercial purposes because they are only present for a brief space of time.

At the outset it was realized that very little was known of the hydrology of the West coast area in which no major hydrological work had previously been done. The Division of Fisheries had therefore to start almost *de novo* in its investigation of this area. It was known that the West coast is under the influence of the Benguela current which flows with northerly and westerly components up the coast, providing conditions for vigorous upwelling near the coast. It was also known that the prevailing southerly winds of summer would set in motion wind-induced currents which would augment this upwelling. Inshore counter-currents were suspected from records of wrecks on the coast. Large reserves of nutrient salts would have to be present to support the flowering of diatoms and the growth of other phytoplankton which form the bulk of the foodstuffs of the very large shoals of adult pilchards present off the West coast.

The area where commercial fishing for pilchards takes place is situated on the continental shelf of the West coast over which flows sea-water which consists of subtropical surface water and a mixture of this water with the upper part of the Antarctic intermediate water. The nucleus of the Antarctic intermediate water is situated in deeper water farther seaward in about 600-800 metres. In its passage from its place of origin, 100-200 miles north of the Antarctic convergence, the Antarctic intermediate water has become mixed with both the overlying and underlying waters so that the properties of this intermediate water have been modified in its passage to the latitudes of the Union West coast. However, it is undoubtedly the high nutrient content of the Antarctic intermediate water which supplies the basic foodstuffs to the surface layer in which lives the dense phytoplankton concentration on which the adult pilchards off the west coast of the Union almost exclusively feed. A certain amount of local dilution by river water from the Berg river which opens into the southern part of St. Helena Bay occurs, particularly in winter.

The commercial catches of pilchards are made in an area stretching approximately from Lambert's

Bay in the north to Stompneus in the south and up to 25 miles seaward from the coast. Early on it was decided to investigate a greater area than this, and therefore a grid of scientific stations was planned in an area stretching from Lambert's Bay to Saldanha Bay and covering approximately the sea area from the coast to the 200 fathom contour. The isobaths radiate northwards and westwards

from a short base line off Saldanha Bay, so that the area covered from the coast to the 200 fathom contour is approximately 80 miles wide at the northern end and 25 miles wide in the south. In this area 18 stations were planned as routine stations to be completed at least once a month; later two more stations were added to fill a gap. Fig. 1 shows the location of the stations.

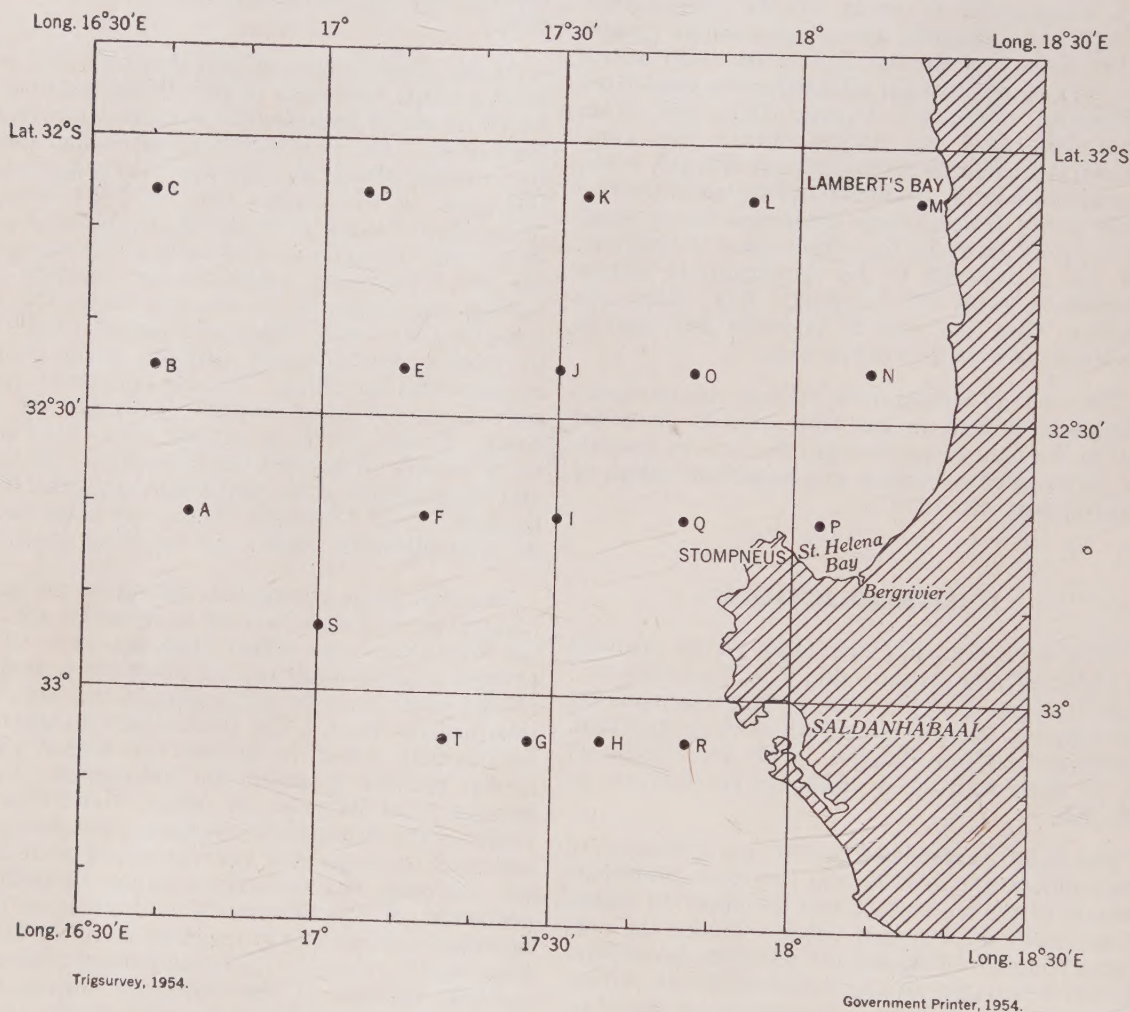


FIG. 1 POSITION OF STATIONS IN ROUTINE AREA

The area covered by the grid of 18 and later of 20 stations, which were occupied each month in the two-year period 1950-52, will be referred to as the routine area throughout this report.

In addition the two smaller ships of the Division of Fisheries, "Schipa" and "Palinurus", made

some 15 stations as often as possible close to the coast mainly for plankton investigations in the immediate vicinity of the commercial fishery. At these auxiliary stations a surface temperature only was taken.

The data on which this report is founded, were

collected mainly in the period April, 1950, to September, 1952, but occasionally data from later months in 1952 and early 1953 are included. In order to fit in with the commercial catch-year which begins on 1st September and ends on 31st August of the following year, the data will be compared on a yearly basis of September through January to August for the years 1950-52.

The vast majority of the salinity and phosphate analyses were made by Mr. A. C. Paterson, Technical Assistant, Division of Fisheries. The phosphate-content values given in this report have been corrected for salt error.

To Dr. J. M. Marchand, Director of Fisheries of the Union of South Africa, who read the manuscript of this report, I am grateful for suggestions and corrections.

This introduction should not be closed without a grateful reference to the scientists and the ships' officers and men without whose enthusiastic help the data could not have been gathered. The west coast of the Union of South Africa is notorious amongst seafaring men for the difficulties of fixing ships' positions out of sight of land. This is due to the high refraction experienced and the frequency of cloudy and foggy conditions which make celestial observations a matter of difficulty. To navigate under such conditions and to occupy a set of fixed positions, voyage after voyage, calls for a very high degree of skill and experience.

3. WATER LAYERS PRESENT IN THE ROUTINE AREA.

The depth of the routine area is nowhere greater than *circa* 450 metres. This fact limits the water masses present to subtropical surface water and a mixture of this water with the upper part of the Antarctic intermediate water whose nucleus (minimum salinity) in these latitudes is, however, situated at depths greater than 450 metres. This means that the mixture of Antarctic intermediate water and subtropical surface water is such that the water at the nucleus of the former never becomes mixed with the lower part of the surface layer. This is important because the Antarctic intermediate current has its maximum phosphate-content near its nucleus.

Fig. 2 shows the T-S diagrams of three stations in April, 1951. They have been selected as representative of conditions in the deepest part in the south-west of the routine area (Station A), a station (J) in the middle of the area, and a coastal station (M) at Lambert's Bay. The numbers on

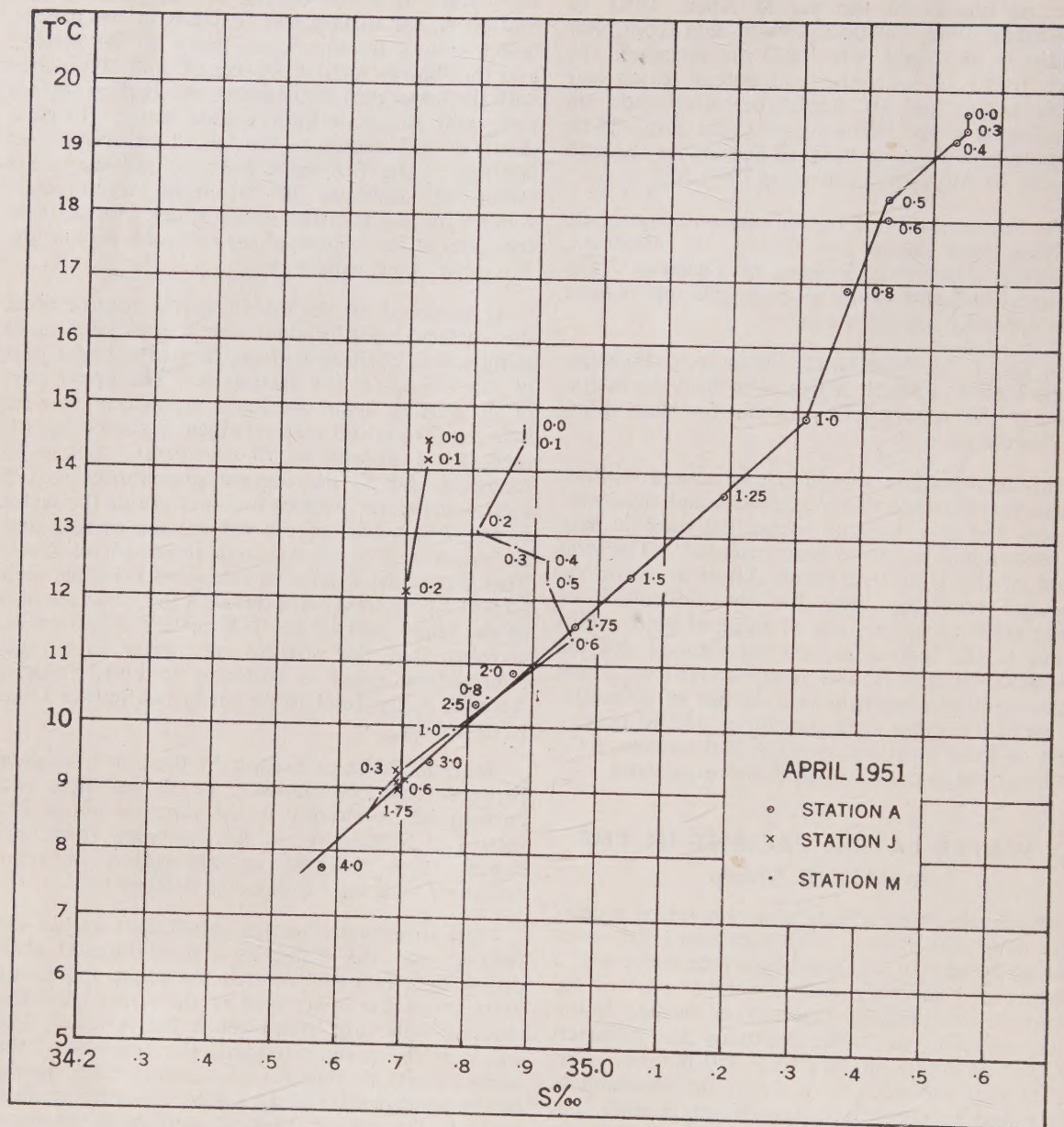
the curves refer to depths in hectometres. At Station A, the surface layer extends to 100 metres, being almost homogeneous down to 30 metres, and then shows mixing between 30 and 100 metres with the upper part of the mixed subtropical surface layer and Antarctic intermediate water. From a depth of 100 metres to the lowest observation at 400 metres the T-S curve is linear and represents increasing amounts of Antarctic intermediate water with depth in the mixed water formed from the water at the bottom of the surface layer and the Antarctic intermediate water.

At Station J, in the middle of the routine area, the surface layer is shallower, corresponding in salinity to a position halfway down the linear part of the T-S curve for Station A. The upper part of the surface layer overlies a subsurface current between 20 and 60 metres which is shown by the increase of salinity at 30-60 metres. Below 60 metres as far as the deepest observation at 175 metres the water present is a mixture of the water in the lowest part of the sub-surface current and the upper part of the Antarctic intermediate water. This part of the T-S curve at Station J (i.e. between 60 and 175 metres) coincides with the lower portion of the linear part of the T-S curve for Station A, showing that the mixture of surface layer and intermediate water is common to both Stations A and J, being closer to the surface at Station J due to upwelling.

Near the coast at Station M the whole column between 0 and 60 metres is nearly isohaline and corresponds in salinity to the water at about 325 metres at Station A; it has upwelled from this depth, being warmed by absorption of solar radiation over the depth range 0-30 metres.

Thus from south-west to north-east across the routine area the water on the continental shelf differs only in that, towards the coast, increasing amounts of the upper part of the Antarctic intermediate water are found below the surface. The water in the surface towards the coast is of the same salinity as that found at sub-surface depths to the south-west, having welled up to the surface towards the coast. Vertical sections of σ_t show that upwelling from seaward is vigorous and extends usually right up to the coastal station, although sometimes there is a dome in the isopycnals between the actual coastal station and the station immediately seaward; this indicates the presence of a coastal counter-current setting to the south as opposed to the more general northerly set usually experienced.

The origin of the subtropical surface water in the routine area is difficult to decide. Two sources



Trigsurvey, 1954.

Government Printer, 1954.

FIG. 2 T-S RELATIONSHIP FROM SW-NE ACROSS ROUTINE AREA

are clearly possible, the South Atlantic ocean and the Indian ocean. South Atlantic subtropical surface water forms the southern part of the large anticyclonic gyral in the South Atlantic ocean and is present as a wide band of water in that ocean between tropical water to the north and the sub-

antarctic surface water in the West Wind Drift in the south. Dietrich (1935, 1) believes that Indian ocean subtropical water from the Agulhas current divides into three branches near the Agulhas Bank: one branch is envisaged as recurving southwards and then eastwards to form the well-known return

Agulhas current, the second penetrating westwards south of the Cape Peninsula into the South Atlantic ocean, whilst the third branch is pictured as passing over and round the Agulhas Bank, round the Cape Peninsula to form a northerly set which eventually becomes mingled with the Benguela current and then loses its identity. Clowes (1950) from a study of T-S relationships and isentropic analysis of data between 20°S to 45°S and from 5°W to 45°E believes that Agulhas water does not *per se* pass the Cape of Good Hope except possibly on rare occasions. If this view be correct, the subtropical surface water found in the routine area would be of South Atlantic ocean

origin. This latter view is supported by evidence from a cruise made in May, 1951 by R.S. "Africana II". Five lines of stations radiating between westwards and southwards from the coast at Cape Columbine, Table Bay, Cape Point, Danger Point and Cape Agulhas were made. In all 42 stations were occupied, the inshore stations being within 2 miles of the coast and the outer one on each line about 190 miles from the coast, in depths greater than 2,000 metres except south of Cape Agulhas where a depth of 1,300 metres was reached at the most southerly station. This network of stations was planned to give hydrological data from both the South Atlantic and Indian

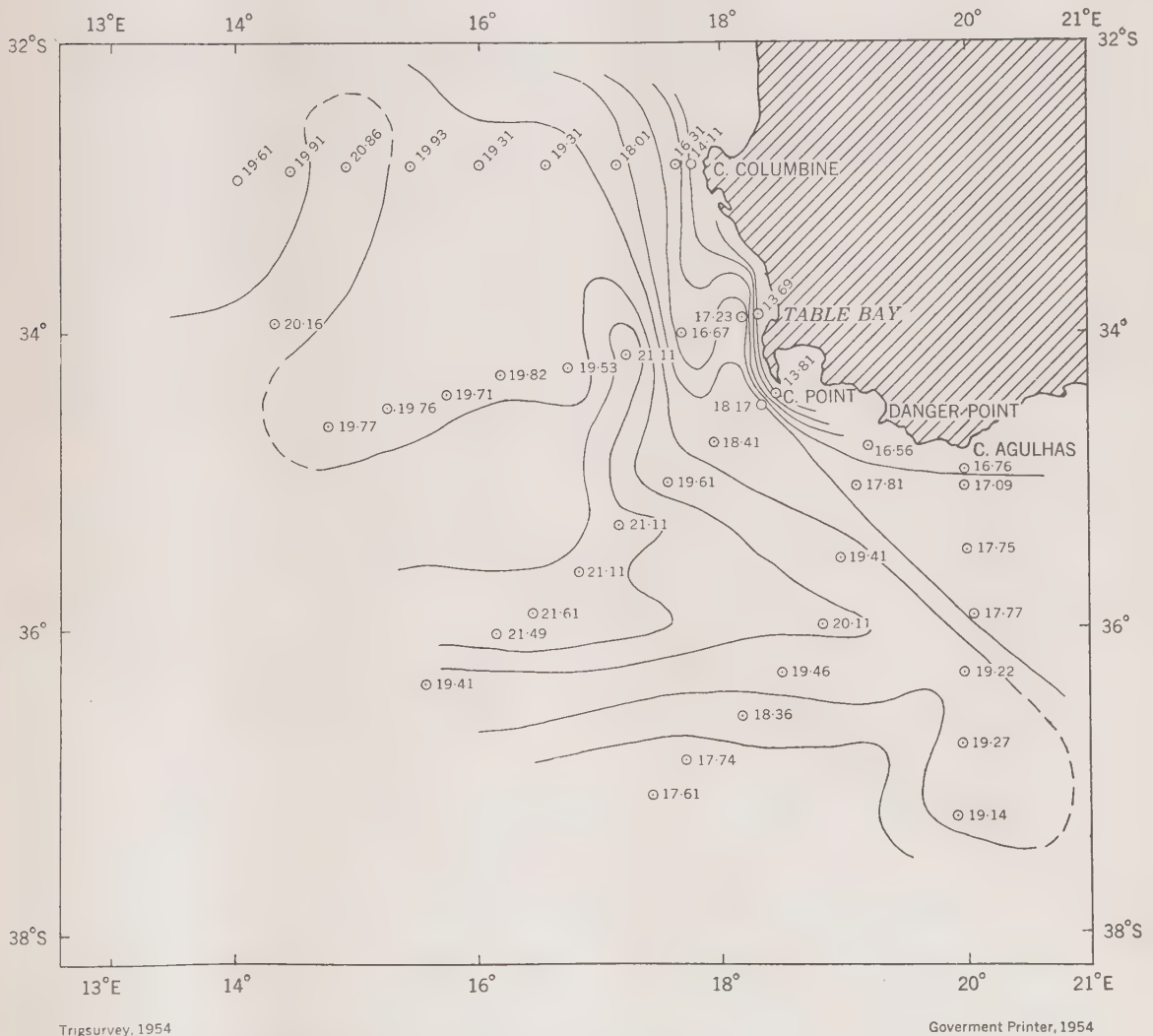


FIG. 3 SURFACE ISOTHERMS. CAPE COLUMBINE TO CAPE AGULHAS. MAY, 1951.

oceans and to find out the influence, if any, of Indian ocean subtropical water in the routine area.

Figs. 3 and 4 show the surface values of temperature and salinity over the area covered by the 42 stations. It can be seen that south of Cape Agulhas, the surface temperatures ranged from

16.76° to 19.27°C and surface salinities from 35.35‰ to 35.55‰. On the lines from Cape Point, Table Bay and Cape Columbine, surface temperatures varied from over 13°C. near the coast to over 21°C, seawards, whilst surface salinities ranged from 34.70‰ near Cape Columbine to over 35.60‰ near the seaward extremities

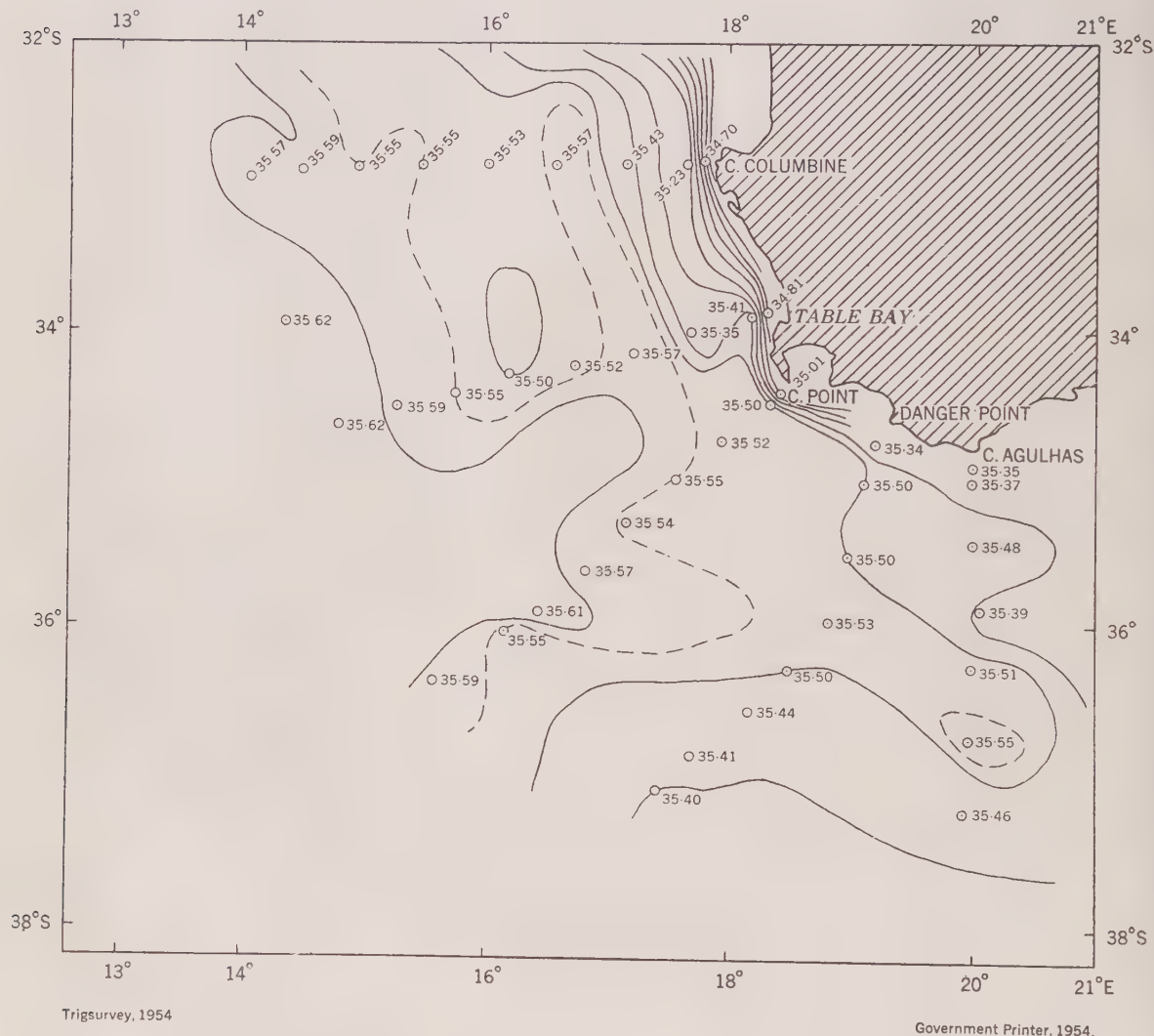


FIG. 4 SURFACE ISOHALINES. CAPE COLUMBINE TO CAPE AGULHAS. MAY, 1951.

of the lines. The isotherms and isohalines in the surface show a thrust of warmer and saltier surface water from the west into the area south of Cape Agulhas. It is a fair assumption to make that the temperature and salinity of the surface

water south of the most southerly station off Cape Agulhas would have been found to be decreasing to values lower than 19°C. and 35.40‰. Thus south of Cape Agulhas the surface water in May, 1951, was of lower temperature and salinity than

to the west and it must be assumed that no penetration of Agulhas water into the South Atlantic ocean occurred; only close to the west coast of the Union was surface water found of lower temperature and salinity than south of Cape Agulhas. This can be due only to intense upwelling in the Benguela current which is admirably shown in Figs. 3 and 4 in the tightly packed isotherms and isohalines in a narrow band of low temperature and salinity beginning close to Cape Point and running northwards parallel with the coast. Thus in May, 1951, the surface water in the routine area off the west coast of the Union was not of Indian ocean origin but probably came from the South Atlantic ocean.

The origin of the high concentration of phosphate found close to the West coast in the St. Helena Bay area is interesting. From a consideration of the hydrological data from the line of stations 1154-1167, 1171-1184 taken by R.R.S. "*Discovery II*" in March-April, 1933 (*Discovery Reports*, 1941), it is clear, that south of the Antarctic convergence, the maximum phosphate is found close to the maximum temperature of the warm deep water at depths *circa* 200-300 metres. A short distance north of this convergence the maximum phosphate is found in the bottom of the Antarctic intermediate layer, as is shown by the phosphate content at the intermediate temperature minimum of this layer. In the south of the subtropical zone, close to the subtropical convergence, the maximum phosphate is found above the intermediate temperature minimum of the Antarctic intermediate layer, but close to the salinity minimum, which is regarded as the core, or nucleus, of this current, and which lies above the temperature minimum. From the southern end of the subtropical zone to as far north as approximately $22\frac{1}{2}^{\circ}\text{S}$, maximum phosphate lies just below the depth of the salinity minimum of the Antarctic intermediate layer. North of $22\frac{1}{2}^{\circ}\text{S}$ as far as the equator, maximum phosphate is found above the salinity minimum of the intermediate layer.

Thus the high phosphate values found in the St. Helena Bay area are due to the high concentration of phosphate in the Antarctic intermediate water with probably considerable local regeneration on the continental shelf close to the coast. North of the Walvis cross-ridge (*circa* $22\frac{1}{2}^{\circ}\text{S}$), which connects with the mid-Atlantic ridge, the high phosphate concentration in the surface layer may be due to the presence of a southward compensation current lying below the Benguela current and above the Antarctic intermediate current in this region. I am indebted to Mr. R. I. Currie of the National

Institute of Oceanography (private communication), who investigated the Benguela current off South-West Africa, for the view that in this region the high phosphate in the surface layer is due to the presence and upwelling of water which flows southward under the Benguela current.

The origin of the Antarctic intermediate water, the nucleus of which is not present in the routine area off St. Helena Bay because the depth is insufficient, is well known as being in the area of mixing 100-200 miles north of the Antarctic convergence. The upper portion of this body of water does, however, in the process of upwelling, affect the temperature, salinity and nutrient salt content of the surface layer in the routine area. Although its origin is known, the path of the Antarctic intermediate water from its point of origin to the routine area is not known. Undoubtedly some of the Antarctic intermediate water in the routine area comes from both the southwest of the South Atlantic ocean and also from the Indian ocean (Clowes, 1950).

4. WINDS.

The following notes are taken from "*Weather on the Coasts of Southern Africa*", Vol. II an official publication prepared by the Meteorological Services of the Royal Navy and the South African Air Force.

The coastline and the mountains between the escarpment and the sea modify the direction of the surface winds which vary from place to place. On the coast the surface winds conform to the trend of the coastline; northerly and southerly on the West coast and easterly and westerly on the South coast.

In summer, when there is a steep gradient from the semi-permanent anticyclone off the west and south-west coasts to the low pressure area over the interior of South Africa, the winds are south to south-west over the Atlantic coast, south-easterly in the neighbourhood of the Cape Peninsula, and easterly to south-easterly from Cape Agulhas to Mossel Bay. This is the windiest time of the year and the season when the Cape south-easters blow.

In winter, when the south-western Cape Province lies in the track of rain-bearing depressions, the prevailing directions are north-west and south-west at Cape Town and west at Cape Agulhas. Winter is less windy than summer, but the coast is liable to be swept by north-westerly gales, which are often followed by equally strong winds from the

south-west. The calmest month of the year is August.

The velocities at Cape Town are highest in December and January, and south and south-easterly winds are stronger than those from any other direction.

December to February is the windiest season. When the atmospheric pressure is low over the interior plateau and high to the west and south, the winds tend to blow parallel to the coastline; south between Olifants River and the Cape, south-east in the neighbourhood of the Cape, and east to south-east along the South coast. At Cape Columbine the south winds are moderate to fresh, and generally stronger than the south-west winds. Over the Cape Peninsula and the adjoining areas, south to south-east winds blow for about 60 per cent of the time day and night in this season. The south-easters are notoriously gusty but are not usually associated with bad weather. North and north-west winds, with a frequency of 15 per cent in these months are next in importance after southerly winds.

March to May is the calmest season, for the south-easters are then fewer and weaker than in summer, and the winter north-westers have hardly begun.

June to August is the season when the winds are affected by the passage of the winter depressions, travelling eastwards in fairly quick succession with intervals of anticyclonic weather between. The winds are thus fairly evenly distributed between north and south on the West coast and between west and south-west on the South coast.

September to November is the season of Spring, the beginning of fine weather. The frequency of winds at Cape Town from south to south-east increases from 25 per cent in August to 55 per cent in November and the mean velocity rises from 3 to 12 miles per hour.

Within 200 miles of the South African coast the winds show approximately the same distribution and seasonal variation as on the coast. In summer the change from the south-east trades to the westerlies takes place between 30°S and 40°S. South of 35°S the strong southerly and south-easterly winds are replaced by winds from south, south-west and west. Towards the end of summer the frequency of south and south-east winds off the West coast decreases and the strong winds are from south-west and west.

Ships report that the force of the Cape south-easter decreases 10 to 15 miles seawards, and the

frequency of south-east gales at sea is considerably less than on the shores of the Peninsula.

In winter the transition from the south-east trades to the westerlies takes place between 25°S and 35°S. South of 35°S the prevailing directions are south-west to north-west.

The spring months are similar to the autumn, but strong winds and gales seem to be more frequent.

5. CURRENTS.

Surface Current.

The British Admiralty *Africa Pilot* (Part II, 1939) makes the following remarks concerning the currents in the neighbourhood of the west coast of the Union of South Africa:—

"An area of high mean atmospheric pressure lies in the South Atlantic ocean in the neighbourhood of latitude 30°S, the longitude of the centre of which varies according to the time of the year. The currents off the west coast of Africa south of the Equator comprise the circulation round the eastern and northern sides of this permanent anticyclone. The Benguela current forms the eastern side of this circulation, flowing northward up the coast to the neighbourhood of the Equator. Here the bulk of the current passes into the South Equatorial current, which flows westward along the northern side of the high-pressure area."

"In the open ocean westward of the Benguela current and south of the South Equatorial current, the water has a general westerly movement, becoming north-westerly in higher latitudes. This is the South-east Trade Drift."

"The Benguela current is a cool current. The low temperature, and probably the greater part of the current flow, comes from the upwelling of the sub-surface water brought about by the south-easterly and southerly trade winds blowing over the coast and the adjoining ocean. The strength of the Benguela current is influenced by local winds. It has a tendency to set a vessel towards the coast during and after strong onshore winds, especially in the neighbourhood of Dassen Island. Between 32°S and Table Bay on the track from off Cape Blanc, 128 observations of set and drift were recorded during the period 1910 to 1922. These show that the frequency of sets with easterly components varied throughout the year. It was greatest in June and July, when the frequency is 40 per cent and 45 per cent, and

was least in March and April when no easterly sets were experienced. The easterly sets were largely influenced by the wind, occurring most frequently with westerly and north-westerly wind. Few of the sets exceeded half a knot."

"The South-east Trades blowing over the coast and the adjacent ocean drive the surface water away from the coast and this is replaced by cooler water from below the surface. Throughout the greater part of the year the water near the coast from northward of Table Bay to latitude 12°S to 18°S is cooler than that farther seaward. In August and September the temperature difference persists up to between latitudes 5°S and 10°S. The region of greatest temperature difference is latitude 26°S to 28°S during the greater part of the year, but in some months extends as far north as latitude 24°S or as far south as latitude 30°S. The average surface temperatures in this region vary from 53°F. (11.7°C.) in September to 60°F. (15.5°C.) in January and February, and the average difference of temperature between the water near the coast and that from 50 to 100 miles offshore may in some months be as much as 7° or 8°(F.)."

"Apart from this temperature difference near the coast, the water of the eastern South Atlantic ocean is relatively cool for a great distance from the coast, as compared with that in the central longitudes of the ocean. This applies more especially to higher latitudes, from 20°S to 34°S."

"The general set of the current southward of the Congo River is parallel with the coast in a northerly direction at the rate of 10 to 15 miles a day; but it is very irregular, both in direction and velocity, for sometimes, between October and June, but principally in March, April and May, the direction of the current is completely reversed, and is found setting southward, and sometimes south-eastward. Thus, close inshore between Cape St. Martin and the Orange river a current has been found setting in a south-westerly direction at the rate of 40 miles a day, and in May and June, northward of Walvis Bay there appears to be a southerly eddy."

"These anomalies generally occur after the rains and northerly winds, but can only be regarded as of an exceptional character; the abnormal current continues for two or three days, but seldom exceeds a week's duration. During calms especially, the currents are very irregular, and not to be depended on, as sometimes they run contrary to their usual direction,

and in the month of July have been known to set south-westward."

The above remarks constitute the experience of many observations gathered over the course of years by the British Admiralty Hydrographer. When R.S. "*Africana II*" began her series of routine voyages it was realized very early from navigational fixes from solar, stellar and land bearings, that at times considerable currents were to be expected in this area, either when due allowance was made for wind and swell, or under calm conditions. The currents experienced were variable in that they were not always found in the same localities or of the same velocity on consecutive voyages. Plates I and II show the currents experienced in the routine area and in the course of the search cruises between Duiker Point and Orange River Mouth respectively. The number of observations is not yet sufficient to enable the currents to be divided into seasonal frequencies; this is particularly so for the autumn and winter months when adverse weather (fog and overcast sky) prevented the taking of sights and land bearings. As may be seen from Plate I the currents experienced in the routine area are mainly directed to the north and north-west. Some north-east setting currents are seen in the vicinity of Station O and in St. Helena Bay, whilst at Station N in the middle of this bay, rotary, anti-clockwise tidal sets have been observed under calm conditions. Occasionally observations showed contrary currents with southerly components to be present, whilst subsequent drift-card experiments showed many instances of southerly directed inshore-setting currents, particularly after northerly winds. In general, the observed currents in the routine area fall into a pattern which may be described briefly as follows: Currents set to the north-north-west along the base line from Saldanha Bay (Stations R to T), northwesterly between Stations T and A, veering to the north again between Stations A and C. In the middle of the routine area the tendency is for the current to set northward from the base line off Saldanha Bay as far as the line of Stations Q to F, where there is a tendency to veer to the north-east into St. Helena Bay. Off Lambert's Bay the sets appear to lie between north-west and north-east. The speed of the currents in Plate I is indicated by the length of the arrows showing the direction of the set. The speeds varied between $\frac{1}{4}$ and 2 knots, the majority being of the order of 1 knot.

On the courses taken during the search cruises for pilchard eggs and larvae, observed currents were as follows (see Plate II). In the south, close to Duiker Point, the current near the coast appears

to set southwards although as will be shown later from drift-card experiments, it must sometimes set to the north. Away from the land in the south the currents are mainly towards the west, but between the outermost station on this southern boundary of the search area and Cape Columbine, the general direction is to the north. As the inside of the routine area was crossed towards the direction of Lambert's Bay, the ship experienced northerly and westerly sets but at Lambert's Bay the current appeared to turn away from the coast towards the north-west as far as nearly 100 miles off Island Point. From this position in towards the land at Island Point the current appears to veer to the north-east except near the land, where the general direction is somewhat confused, some sets being directed towards the land and some away. From Island Point north-westward to 100 miles west of Melkbos Point the current again sets to the North-west but near Melkbos Point itself there was no general pattern of direction, currents in all directions being observed at different times. The current again set to the north-west between Melkbos Point and 100 miles west of the land between Port Nolloth and Orange River Mouth, whilst from this outer position inwards to the coast the current direction was mainly to the west and north, except near the coast, where southerly and easterly sets were found.

The above brief description of the currents experienced during a series of 14 cruises each of 10 days duration between Duiker Point and Orange River Mouth shows that away from the land the general direction of the current is to the west and north-west, but close inshore, particularly off Duiker Point, Island Point, Melkbos Point and Port Nolloth, the currents are more variable and often set to the south or even in towards the land. It is this variable inshore-setting current which has been the cause of numerous strandings and wrecks on this part of the coast. In times of bad visibility—and the coast is notorious for the frequency of fog—ships find themselves too close to the coast for safety and on occasion strand.

In order to augment the information on currents obtained from navigational observations, the opportunities for which depend to a large degree on weather conditions, it was considered necessary to try a series of drift-card experiments with particular reference to inshore currents. Drift-cards in sealed plastic envelopes were liberated at fixed positions at sea, ten cards being released at each station made per cruise. These drift-cards float in the surface and, lying flat, do not offer any surface above the water for resistance to the wind. It was hoped that a reasonable percentage

of these would strand on the west coast of the Union providing they did not get too far away from the land and so be borne northward and westward away from the coast. Bearing in mind the sparsely populated areas of the West coast, the returns of stranded cards through the co-operation of the general public who pick them up on the beaches, are not discouraging. Up to date, from a total of 4,040 cards liberated between Duiker Point and Orange River Mouth, 102 have been found on the beaches of the West coast, a return of over 2½ per cent. In addition to the fact that the West coast is a sparsely inhabited area, it must be remembered that cards liberated at the outer stations some 60–80 miles off the coast have probably drifted north and west and may even have travelled into the South Equatorial current and been carried westward across the South Atlantic ocean.* So far no card liberated more than 46 miles off the coast has been returned, the majority of returns being from those liberated less than 25 miles from the coast. One disadvantage of this method of showing current movements is that no idea of the course taken by a particular card can be known for certain, and that even after a great number of liberations and strandings, it will only be possible to suggest probable movement courses. Also, because the card may strand and not be picked up for a considerable time subsequently, or even be caught up again by the sea at high spring tides and later again cast ashore, only a minimum speed of movement can be calculated from the time interval between dates of liberation and finding. So far the greatest distance in a direct line between point of liberation and that of recovery is 164 miles, this card being found 57 days after liberation. This works out at a minimum speed of nearly 3 miles per day. The highest minimum speed so far recorded is about 6·7 miles per day, or just over ¼ knot. The proportion of returned cards which have travelled northwards to those stranding south of the point of liberation is, at the time of writing this report, approximately 4 to 5. The number found south of their point of liberation is greatly increased during a period of northerly winds. Plate III shows the positions from which the returned cards were liberated and the places on the coast where they stranded. It will be seen that the 102 returned cards give evidence for coastal currents which mostly set in towards the shore. The importance of this evidence is con-

* Since the above was written, confirmation of the possibility of a drift-card liberated off the West coast of the Union of South Africa and stranding on the East coast of South America has been obtained. A bottle containing an identifying label was liberated from R.S. "Africana II" in 33° 00' S, 08° 55·2' E, some 450 miles west of Saldanha Bay in June, 1951. This bottle was stranded at Vizeu at the mouth of the Rio Gurupi on the Brazilian coast at the border of the States of Para and Maranhao and picked up some time in August, 1953.

sidered to be great. For many years it has been a matter of conjecture as to how the Cape Rock Lobster (*Jasus lalandii* Milne-Edwardes) maintained the strength of its population on the west coast of the Union in view of the known northward and westward sweep of the Benguela current, which would tend to transport away from the coast the plankton stages of this species. During cruises westward of Dassen Island the biologists of R.S. "*Africana II*" have found quite large specimens of the *phyllosoma* stage of the Cape Rock Lobster, and on occasions specimens were found over 1,000 miles from land. In the circumstances it is difficult to understand how the larval stages of the Cape Rock Lobster, which are at first planktonic, and later demersal organisms, can return to the West coast as young rock lobsters. However, the fact that within at least 46 miles from the West coast the presence of inshore-setting currents has been demonstrated from the return of drift-cards, does suggest a possible method of return to the coast of some of the planktonic forms which do not get swept too far away from the coast. A similar method of return of fish eggs and larvae is also possible. It is not intended to suggest that such a method of return of planktonic stages of invertebrates and fish is the only method. Much more data, both hydrological and biological are needed before any further conclusions can be drawn.

Subsurface Current.

The presence of a subsurface current in the routine area is often shown by an increase of salinity below the actual surface of the sea. The layer of increased salinity occurs in the depth range of 10 to 200 metres, but usually over a much narrower range, 20-60 metres. The nucleus of the current as shown by the maximum salinity of the layer of increased salinity, occurs most frequently at a depth of 30 metres and also most frequently in the depth range 20-60 metres. On very few occasions the presence of the subsurface current is also shown by a temperature inversion, but on no occasion has the density of the layer of increased salinity been such, that an inversion of density, or a state of instability, existed. The subsurface current occurred more frequently in the calendar year 1952 than in 1951. Seasonally the frequency of occurrence was highest in summer and least in winter and, on a comparative basis of one routine cruise per month, the frequencies for the four seasons were: summer 110, autumn 61, winter 27½ and spring 46½. The frequency was highest in summer-autumn in 1951 and in spring-summer in 1952.

At stations where the depth is greater than *circa*

100 fathoms the subsurface current tends to be present only in the summer months of the year. Between the coast and approximately 100 fathoms, although the frequency of occurrence in summer is double that of any other season, it does occur in winter to the extent of about a third of the summer frequency. The area from the coast to the 100 fathom line excludes stations H, F, E, D, C, B, A, S, T and G, and it is at these stations that the tendency exists for the subsurface current to be absent in winter. Inside the 100 fathom line the current tends to occur in all seasons, but the occurrence here is maximal in summer and minimal in winter. The frequency of occurrence of the current increases from the west until the coastal stations in St. Helena Bay are reached when the number of occurrences falls rapidly.

Plotted as a frequency per month over the period July, 1950-March, 1953, the curve is almost smooth with a maximum in late summer (February) and a minimum in mid-winter (July). It would appear from this seasonal frequency that the occurrence of a subsurface current in the routine area is connected with the season of southerly winds, i.e. summer, but that it can also occur with much less frequency in winter when northerly and westerly winds blow.

The existence of the subsurface current is shown by salinity increases and very rarely by temperature differences. Unfortunately it has not been possible to estimate oxygen-content which might also have shown the presence of the current.

Fig. 5 is a vertical section of salinity on the line of stations A, F, I, Q and P in February, 1953, when upwelling was vigorous during a period of strong southerly winds, and when the average surface temperature and salinity in the routine area were 2·5°C. and 0·07‰, respectively, lower than in the previous month. The subsurface current may be seen at Stations A, F and I with the highest salinity in the nucleus of the current at 60 metres at Station A, some 77 miles west of St. Helena Bay. At Stations F and I the course of the isohalines above about 20-40 metres appears to show a movement seawards of relatively low salinity water from the direction of the coast; below this movement, the increased salinity of the subsurface current is shown as far down as about 90 metres. It would seem that the subsurface current acts as a partial replacement for the water drawn away from the coast and is additional to the upwelling of water from lower depths which is shown in the section between Stations A and Q. There is evidence for sinking of the water drawn away from the coast as the course of the 34·90‰

isohaline at Station F shows. There is no doubt that the process of upwelling, which is increased by southerly winds, is more complex than was considered earlier. Some discussion of upwelling follows in the next chapter.

6. UPWELLING.

Before the phenomenon of upwelling is considered, a few introductory remarks must be made

concerning the conditions under which upwelling takes place.

In the southern hemisphere, when a current flows alongside a coast in such a direction that the coast is on the *right-hand* side of the direction in which the current is moving, the layers of equal density in a vertical section at right angles to the coast will be tilted upwards to the surface from seawards towards the coast. This means for

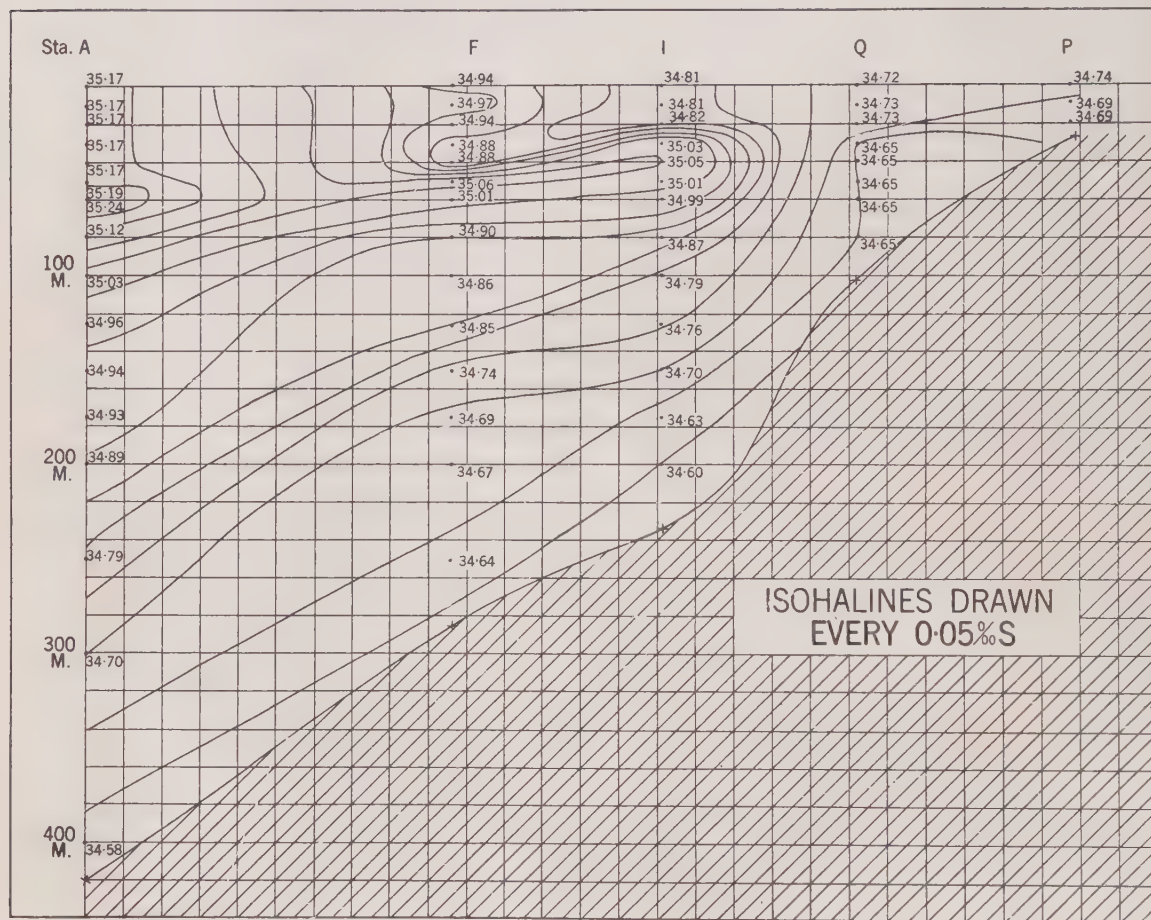


FIG. 5. VERTICAL SECTION OF SALINITY FROM WEST TO EAST ACROSS ROUTINE AREA.
FEBRUARY, 1953.

Trigsurvey, 1954.

Government Printer, 1954.

instance, that in the Benguela current flowing northwards up the west coast of the Union, the lighter water will be found seawards and heavier water close inshore, providing no counter-current is flowing close to the shore.

Conversely, also in the southern hemisphere, if the current direction is such that the coast lies on the *left-hand* side of the direction in which a current is moving, the layers of equal density in a vertical section normal to the coast will tilt downwards

from the surface of the sea from seawards towards the coast. This means that when an inshore counter-current is flowing southwards along the West coast, but inside the Benguela current, lighter water will be found close to the coast and heavier water more seaward. A line of divergence will exist between the northward flowing Benguela current and the inshore counter-current; along this line of divergence upwelling must occur, a phenomenon which is discussed below.

Sverdrup, Johnson and Fleming (1942) describe the action of the surface winds in producing currents. They state that the effect of the wind on ocean currents is twofold; first, the stress that the wind exerts on the surface of the sea leads directly to the development of a shallow wind drift; in the second place, the transport of water by the wind drift leads to an altered distribution of density and the development of corresponding currents.

In the case of the wind drift, only frictional forces and the force due to the earth's rotation are important. The wind exerts a stress on the sea surface which sets the surface layer in motion, which in turn exerts a stress on the underlying layer and sets this in motion and so on. When, however, water is set in motion, it becomes acted on by the force of the earth's rotation which, in the southern hemisphere, acts to the left of the direction in which the water is moving. The result is that the wind drift at the surface is directed 45° to the left of the wind direction in the southern hemisphere. With increasing depth the angle between the wind and the current increases and the velocity decreases. Such a wind drift can only develop fully in the open ocean in regions where the wind blows in the same direction and with the same velocity over wide areas. Near coasts and near regions of wind shifts, modifications arise and the secondary effect of the wind becomes important. Consider a wind in the southern hemisphere blowing parallel to a coast which is on the *left hand* side of an observer with his back to the wind, and assume that the density of the water increases with depth. The direct effect of the wind leads to a transport of light and warm surface water towards

the coast, but, because the coast represents an obstruction to the flow, the light and warm surface water becomes piled up against the coast and, at some distance away, denser and colder subsurface water must rise to replace the amount that has been carried towards the coast. Consequently, the distribution of density becomes altered and, as a secondary effect, a current develops which flows in the direction of the wind. Such an effect of the wind develops on the west coast of the Union in winter when the prevailing winds are northerly, causing a current to flow inshore in the direction of the wind, i.e. to the south.

On the other hand, in summer, the prevailing winds on the west coast of the Union are southerlies and the coast lies on the right-hand side of the direction in which the wind is blowing. Light and warm surface water is then transported away from the coast and is replaced by denser and colder subsurface water. This process, which is known as *upwelling*, also leads to an altered distribution of density to which a current flowing in the direction of the wind corresponds. Experience shows that the upwelling is restricted to shallow depths, and its effect can be traced only to depths of 100–300 metres. Upwelling has been studied extensively, partly because the cold subsurface water which is drawn up to the surface exercises a great influence upon the climates of the coasts where upwelling occurs, and partly because the upwelling water is rich in plant nutrients which form the basic foodstuffs of fish and indeed of all the fauna of the oceans. Regions of upwelling are therefore regions of high productivity as is the west coast of the Union of South Africa.

The Benguela current, a current related to the distribution of density, flows northwards and westwards off the west coast of the Union. Light, warm water is found in the surface seaward of the current and heavy, cold water towards the coast. Water from subsurface depths wells up to the surface near the coast and brings plant nutrients into the euphotic zone ready for the phytoplankton to utilize.

In winter close to the west coast of the Union the process of upwelling tends to be diminished

because the prevailing wind directions are north-westerly to south-westerly and the effect of the wind is to induce a current in the direction of the wind. This current is associated with a distribution of density such that light and warm water is found close to the coast, more particularly when the wind direction is between north and west. On the other hand in summer, with prevailing southerly winds (more particularly between south and east) the process of upwelling caused by these winds is associated with a density distribution such that light and warm water is found off-shore and heavier, colder and nutrient rich water is found close to the shore. Thus the prevailing northerly to westerly winds of winter tend to decrease upwelling associated with the Benguela current, whilst in summer with prevailing winds in the south to east quadrant, the upwelling due to the Benguela current is augmented by the current induced by the surface winds.

Currie (1953) discusses upwelling in the Benguela current off South-West Africa on the basis of data from two surveys made under differing conditions of surface wind in 1950. One survey was made in March, 1950, in conditions of calm or light winds, the second in September–October, 1950, in conditions of strong winds. Currie shows the distribution of surface isotherms as being very irregular and suggests that the interlocking tongues of relatively cool and warm water are due to irregular upwelling of cool water at separated points along the coast. He finds there are two distinct surface waters present: An inshore one of salinity *circa* $35.00/_{00}$ or less and an offshore water of salinity *circa* $35.20/_{00}$. A fairly sharp boundary is present between these different surface waters although in places mixing occurs. The inshore water has, in general, similar properties to the water farther offshore at subsurface depths. On both surveys a well-defined homogeneous surface layer was present offshore, separated from the underlying water by a strong temperature discontinuity. Inshore, considerable variation was shown; during the first survey no such homogeneous layer was present and strong heating had apparently taken place at the surface, but during the second survey there was a thin homogeneous surface layer overlying a weak

discontinuity. This difference indicates the contrasting effects of the calm conditions of the first survey and the strong winds during the second survey.

Currie (*loc. cit.*) further states that because in the core (salinity minimum) of the Antarctic intermediate layer off South West Africa only 50 per cent of the original water type remains, and this at a depth of more than 600 metres, only a relatively small proportion of Antarctic intermediate water is subject to the upwelling which does not extend much below 300 metres. Dynamical treatment of the data shows that in the period of weak winds a general movement occurs to the north with a rather weak southerly movement inshore. In the period of strong winds a series of horizontal eddies is shown to be present inside a much stronger northward flow.

Currie quotes Sverdrup (1937–38) who, in describing the process of upwelling off the Californian Coast (an area comparable with the west coast of the Union and South-West Africa), writes that during the first part of a period of upwelling the light surface water is banked up at some distance from the coast. Between the heavier upwelled water and the light offshore water a boundary region forms with a strong current parallel to the coast. This boundary region moves away from the coast, but so slowly that it acts as a barrier against the outward transport of the upwelled water. Inside this barrier a cellular circulation develops which, since the offshore boundary moves away from the coast, is being fed from below. This appears to be the initial stage, but as the boundary region moves out, conditions become more and more unstable and large eddies develop on the coastal side of the boundary. Sverdrup postulates a somewhat similar circulation cell outside the region of the current. He pictures the barrier of the boundary region as a secondary coast, with ascending motion near the barrier restricted to the upper layer of light water, i.e. the vertical movement here has not the character of upwelling because no deeper water is brought to the surface. Below the top layer he considers vertical movement occurs which feeds the current which flows towards

the coast below the boundary layer. Sverdrup concludes by saying that the processes are far more complicated than are assumed on the basis of earlier data. It is evident that surveys designed to investigate further the phenomenon of upwelling off the west coast of the Union are clearly needed. Close correlation with the Union Weather Bureau will be necessary. The surveys should be repeated over and over again under different conditions of

surface winds and it is suggested that these surveys be made in the months of autumn and spring since, in these seasons, the surface winds change from summer to winter conditions and *vice versa*. To date the Division of Fisheries has not been in a position to do this owing to staff shortages. However, some preliminary observations have been made, but the data have not been treated hydrodynamically.

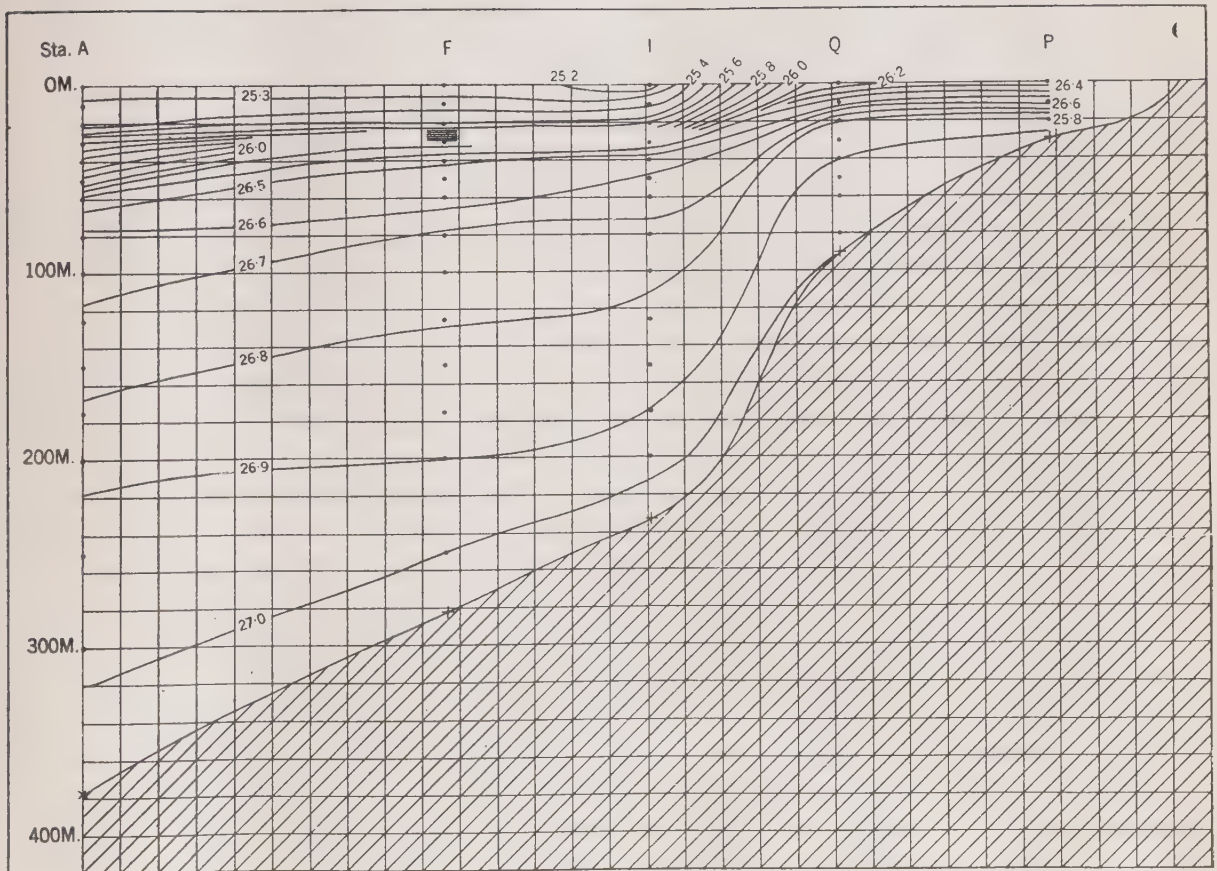


FIG. 6. VERTICAL SECTION OF σ_t FROM WEST TO EAST ACROSS ROUTINE AREA.
JANUARY, 1953.

Early in 1953 R.S. "*Africana II*" made cruises March and in the course of these cruises the in the routine area in January, February and following winds were recorded:—

TABLE 1.

Winds from (Direction True).	January.		February.		March.	
	Frequency.	Average Beaufort Force.	Frequency.	Average Beaufort Force.	Frequency.	Average Beaufort Force.
001°-090°.....	—	—	—	—	—	—
091°-180°.....	8	3·0	14	4·4	4	3·0
181°-270°.....	7	2·7	4	3·5	14	2·7
271°-360°.....	2	1·0	—	—	—	—
Calm.....	3	0·0	2	0·0	2	0·0

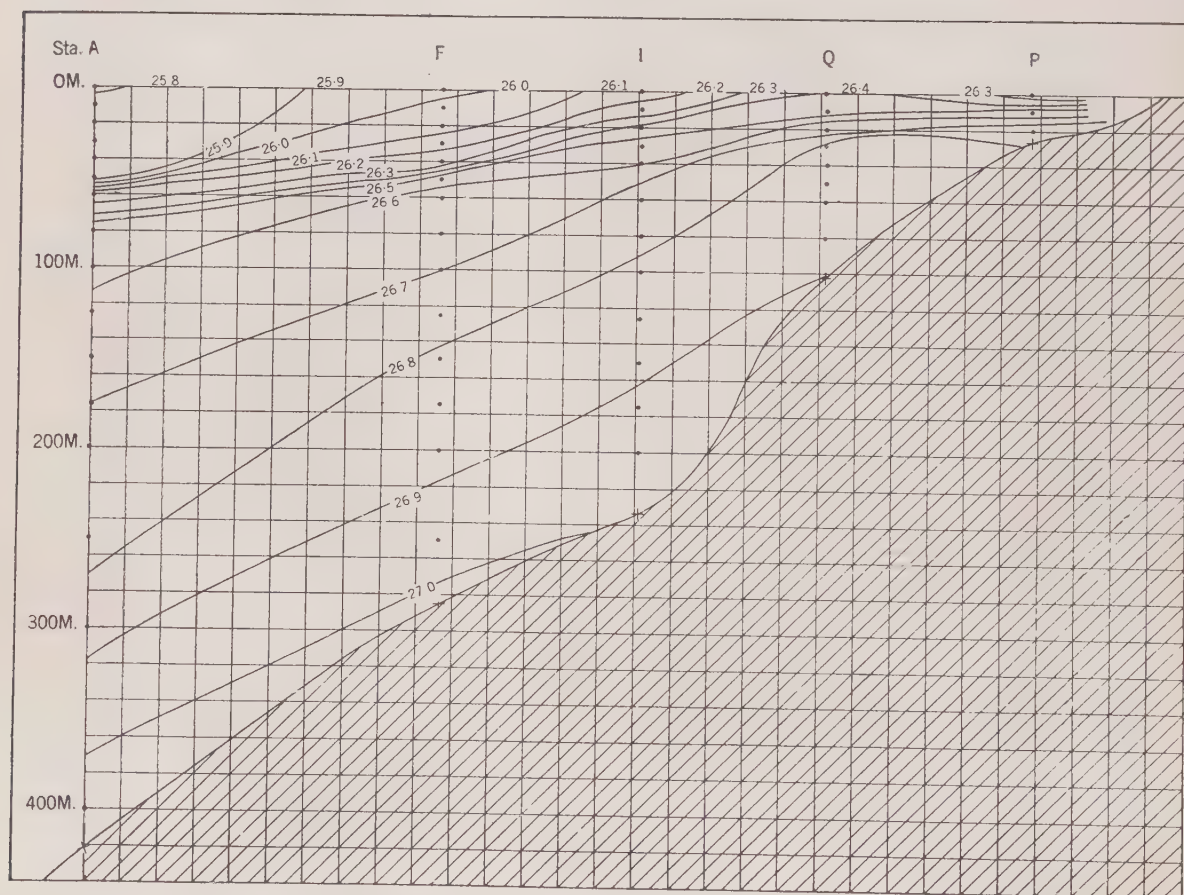


FIG. 7. VERTICAL SECTION OF σ_t FROM WEST TO EAST ACROSS ROUTINE AREA. FEBRUARY, 1953.

Thus the cruise in February stands out as occurring during a period of strong winds compared with the cruises in the other two months, all the winds occurring in the east to south and south to west quadrants, but mainly from east to south and stronger in this quadrant. In January, 15 of the winds recorded were also in these two quadrants but weaker, and about equally divided between south-east and south-west. In March, on the other hand, south-westerly winds of Beaufort Force between 2 and 3 predominated. The average surface temperature and salinity in the routine area in these three months were as follows:

January, 17.10°C. , 34.98‰ , February, 14.64°C. , 34.91‰ and March, 17.12°C. , 34.87‰ . Thus in February the average surface temperature and salinity were relatively much lower than in January, but by March the average surface temperature had recovered to the January value although the salinity was still lower than in January and February.

Vertical sections of σ_t along a line of stations A, F, I, Q, P, across the routine area in the cruises during the above three months are shown in Figs. 6 to 8.

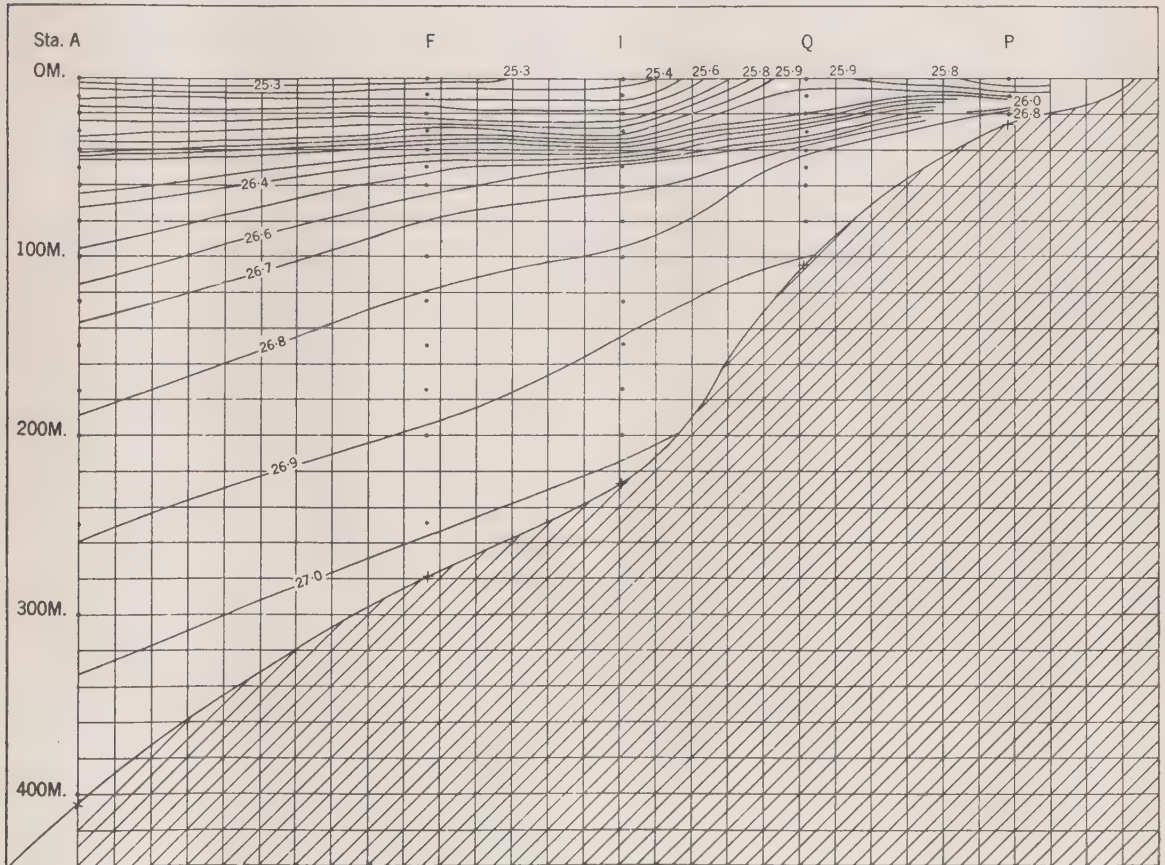


FIG. 8. VERTICAL SECTION OF σ_t FROM WEST TO EAST ACROSS ROUTINE AREA.
MARCH, 1953.

Trigsurvey, 1954.

Government Printer, 1954

The sloping upwards to the sea surface from seaward towards the land of the isopycnals illustrates the extent of the upwelling which occurs off the west coast of the Union. Thus during the

January and March cruises, water of density corresponding to $\sigma_t = 26.9$ was found at a depth of 220–260 metres at the outermost station, A, and at depths of 40–100 metres at Station Q, some six miles

from the nearest land (Cape Columbine). In the February cruise, however, the depth of this water at Station A was nearly 320 metres whilst at station Q water of the same density ($\sigma_t = 26.9$) was found at 160 metres.

The chief difference in the observations during the three cruises occurs in the upper 30–40 metres. During the January and March cruises the isopycnals were closely packed in the 0 to 30–40 metres layer and were almost horizontal from Station A

to Station I, sloping up to cut the surface of the sea between Stations I and Q. In the February cruise they were farther apart, were not horizontal in the depth range 0 to 30–40 metres and sloped upwards to cut the surface over a much greater distance, i.e., from Station A to Station Q. In February, at Station A the 0–50 metres layer was nearly homogeneous and the water in this layer had been subjected to vigorous vertical mixing.

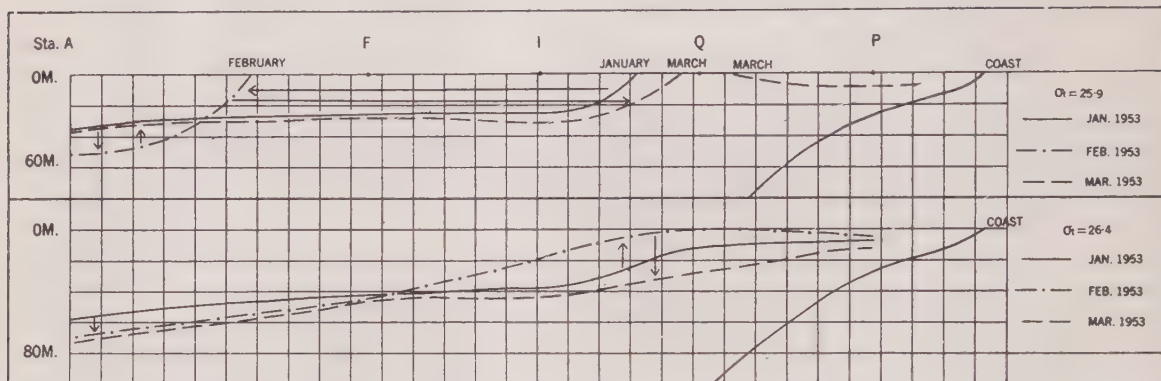


FIG. 9. POSITION AND DEPTH OF TWO ISOPYCNALS FROM WEST TO EAST ACROSS ROUTINE AREA. JANUARY-MARCH, 1953.

Trigsurvey, 1954.

Government Printer, 1954.

The difference in the depth and the course of two isopycnals, $\sigma_t = 25.9$ and $\sigma_t = 26.4$, in the three cruises is shown in Fig. 9, the arrows indicating the character of the motion which may have brought about the distribution in succeeding months. In the interval between the January and February cruises the water of density $\sigma_t = 25.9$ has been transported seawards and replaced by heavier water towards the coast. The deeper water corresponding in density to $\sigma_t = 26.4$ has moved closer to the surface between Stations F and P in the period January to February, but has taken up a position about 10 metres deeper at Station A over the same period. Between the February and March cruises the water of density $\sigma_t = 25.9$ moved back almost to the same depth and position as in January whereas the deeper water of density corresponding to $\sigma_t = 26.4$ was present at lower depths particularly at Station I and Q in March.

Fig. 5, a vertical section of salinity in February, 1953, which was used to show the existence of the subsurface current, also shows a movement of

water in the upper 20–40 metres from coastwards to seawards.

7. TEMPERATURE, SALINITY AND IN-ORGANIC PHOSPHATE-CONTENT OF THE SURFACE LAYER IN THE ROUTINE AREA IN THE TWO COMMERCIAL-CATCH YEARS 1950–51 AND 1951–52.

The average surface temperature, salinity and inorganic phosphate-content at each of the twenty stations in the routine area throughout each year were calculated. By summing and averaging these yearly averages, a mean yearly value was obtained for the surface T° , S°_{00} and P-content for the routine area considered as a whole; these mean yearly values are given below:—

TABLE 2.

September, 1950–August, 1951.			September, 1951–August, 1952.		
T°C.	S‰	P(mg-atoms P/m ³).	T°C.	S‰	P(mg-atoms P/m ³).
15.56	35.08	0.64	15.42	35.11	0.59

Thus taken as a whole area (Stations A–T), the yearly averages show that the water in the surface was colder and saltier but of lower inorganic phosphate-content in 1951–52 than in 1950–51. The differences in the two years are small, being 0.14°C., 0.03‰ S and 0.05 mg-atoms P/m³

respectively.

Table 3 shows the corresponding figures of yearly averages for the whole area of the mean integral values of the 0–50 metres layer in the two years under review.

TABLE 3.

September, 1950–August, 1951.			September, 1951–August, 1952.		
T°C.	S‰	P(mg-atoms P/m ³).	T°C.	S‰	P(mg-atoms P/m ³).
14.32	35.07	0.93	14.21	35.10	0.90

Thus the yearly averages of the mean integral values of the 0–50 metres layer also show that the water in the upper 50 metres was colder and saltier but of lower phosphate-content in 1951–52 than in the earlier year 1950–51. The differences are again small, being 0.11°C., 0.03‰ S and 0.03 mg-atoms P/m³ respectively.

Although the actual differences in the two years for the routine area taken as a whole are small, the differences at some individual stations are significant. Plates IV and V show the differences (1950–51 minus 1951–52) for temperature, salinity and phosphate-content at individual stations in the routine area in the surface and 0–50 metres layer respectively. The shaded areas in both figures show the areas in which the yearly averages are greater in 1951–52 than in 1950–51, the negative sign in front of values in the shaded areas showing that these particular values were greater in 1951–52 than in 1950–51. The figures are contoured at intervals of 0.5°C., 0.05‰ S, and 0.05 mg-atoms P/m³.

The most significant differences in the yearly averages of temperature in the sea surface are the marked rise of temperature in 1951–52 at the southern end of the routine area (Stations R, H

and G) and the lowered temperature in the remainder of the area (except at Station E) in the same year, particularly in the St. Helena Bay area (Stations I, M, N and P) and at Stations S and A in the deeper area which exists in the south-west of the routine area. Turning now to the yearly averages of surface salinity the chief feature is the higher salinity in 1951–52 everywhere except at the northern and middle stations in St. Helena Bay (Stations M and N), Station I, and at Stations S and A in the deeper area in the south-west of the routine area. This higher salinity in 1951–52 is particularly noticeable at the southern end of the routine area at Stations H and G where, at the latter station, the salinity average was 0.23‰ higher in 1951–52. When the yearly averages of surface phosphate-content are considered it is seen that at the majority of stations the phosphate-content in 1951–52 was lower than in 1950–51. In 1951–52 this is seen particularly along the southern edge of the routine area (Stations T, G, H and R) and at Station P in the south of St. Helena Bay. On the other hand, the shaded area in Plate IV shows that at the northern end of St. Helena Bay (Station M), the yearly average of phosphate was 0.45 mg-atoms P/m³ higher in 1951–52 and at Station Q it was 0.14 mg-atoms P/m³ higher in the same year.

The differences between the yearly averages in 1950-51 and 1951-52 of the 0-50 metres layer are shown in Plate V. The southern and central parts of the routine area were warmer in 1951-52 than in 1950-51; this was particularly so at the southern edge of the area (Stations G, H and R). Thus at Station G the yearly average was as much as 1.03°C . higher in 1951-52. The remainder of the area, consisting of the north-eastern and western sides, was colder in 1951-52. The salinity averages show that everywhere, except the western side of the area (Stations S, A and B) and at Station M in the northern end of St. Helena Bay, the area was more saline in 1951-52; this was particularly so at the southern end of the area (Stations T, G and H), where at Stations G and H the average yearly salinity was as much as 0.17‰ higher in 1951-52. At the majority of stations the phosphate-content was lower in 1951-52, particularly at the southern end of the area (Stations T, G, H and R), where, for instance, at Station G the yearly average was as much as $0.21\text{ mg-atoms P/m}^3$ lower in 1951-52. On the other hand the phosphate-content at stations running in a line south-west from the northern end of St. Helena Bay (Stations M, N, L, J and F) was considerably higher in 1951-52 than in 1950-51. The phosphate-content in the 0-50 metres layer at the station nearest the coast, M, when considered as an average over a year was as much as $0.21\text{ mg-atoms P/m}^3$ higher in 1951-52 than in 1950-51.

Both the surface and the 0-50 metres layer yearly averages show a broad agreement of those positions in the routine area where the differences in the yearly averages are significant: The yearly averages also demonstrate that although the area considered as a *whole* does not show great differences in temperature, salinity and phosphate-content between the two years under review, relatively large differences are apparent at individual places within the area. It is possible that these relatively large differences may be significant to the breeding and feeding of the pilchard stocks within the area. Thus the phosphate-content in the surface at Station M, which was $0.45\text{ mg-atoms P/m}^3$ higher in 1951-52 than in 1950-51, undoubtedly presented a much larger amount of this nutrient for the growth of the phytoplankton population present at this position in 1951-52. Adult South African pilchards feed almost exclusively on diatoms, and thus it is conceivable that the increased phosphate present in 1951-52 would have presented a more favourable condition for the production of an increased phytoplankton population, and so an increased supply of food for adult pilchards in that year.

In an endeavour to ascertain whether the differences of temperature, salinity and phosphate-content at individual stations in the routine area during the two years under review can be related to differences in season of the year, averages for spring, summer, autumn and winter were calculated. In this connection spring was regarded as September, October and November, summer as December, January and February, autumn as March, April and May, and winter as June, July and August. This division into seasons is not ideal because it takes no account of early or late seasons but it is considered to be the best available. Plates VI to VIII show the seasonal variation of temperature, salinity and phosphate-content for the surface, and Plates XII to XIV those for the 0-50 metres layer, each element being considered as a separate figure which shows the seasonal averages for individual stations in both years.

Plate VI shows the seasonal variation of surface temperature in the two years, the 15°C . isotherm being thickened and the area $> 15^{\circ}\text{C}$. being shown by hatching. In 1950-51 the mean surface temperature of the routine area taken as a whole rose from 15.49°C . in spring, through 15.67°C . in summer to a maximum of 16.00°C . in autumn, to fall to a minimum of 14.85°C . in winter. 1951-52 differed from the previous year in that the mean surface temperature for the whole routine area increased from a minimum of 14.47°C . in spring to a maximum of 16.63°C . in summer to fall to 15.85°C . in autumn and 14.72°C . in winter. In all seasons in both years the temperature gradient was from high seawards to low coastwards.

In the spring of 1950-51 the surface of the sea in the middle and western parts of the routine area had a temperature of 15° - 17°C ., whereas in the same season in 1951-52 cooler water was present, the surface temperature never rising above 15.60°C . in the west whilst St. Helena Bay was approximately 1°C . cooler in 1951-52.

In summer, 1951-52 was in the main, warmer than 1950-51, surface water of 15° - 19°C . temperature occupying most of the area in 1951-52. In particular the warmer water in the summer of 1951-52 can be seen as a thrust towards the coast along the southern limit of the area. Thus at Station R, near Saldanha Bay, the average surface temperature in the summer of 1951-52 was as much as 4°C . higher than in summer 1950-51.

In the autumn, the average surface temperature was slightly higher in 1950-51 than in 1951-52, the chief differences being the presence of surface

water $> 19^{\circ}\text{C}$. to the south-west in 1950-51 and surface water 2°C . colder in 1951-52 than in 1950-51 close to Lambert's Bay. The presence of warmer water along the southern edge of the area which was first seen in the summer of 1951-52 was again seen in autumn of the same year.

In winter, 1950-51 was also slightly warmer than 1951-52, the chief difference in the two years being the cooler water in 1951-52 in St. Helena Bay. The outstanding differences in the seasonal variation of surface temperature in the two years are the presence of cooler water everywhere in the spring of 1951-52, the increased temperature along the southern edge of the area in the summer of 1951-52, the continued presence of warmer water along the southern edge of the area in autumn 1951-52, and the presence of much colder water off Lambert's Bay in the same year and season and also in the whole of St Helena Bay in the winter of 1951-52.

Plate VII shows the seasonal variation of surface salinity in the two years, the $35\cdot40\text{‰}$ isohaline being thickened and areas of greater salinity than $35\cdot40\text{‰}$ being shown by hatching. In 1950-51 the mean salinity in the surface of the whole area was at a maximum in spring ($35\cdot17\text{‰}$) falling to a minimum in summer ($34\cdot99\text{‰}$), to rise gradually through autumn ($35\cdot04\text{‰}$) and winter ($35\cdot13\text{‰}$). In 1951-52 the mean salinity of the surface water in the whole area was again at a maximum in spring ($35\cdot19\text{‰}$) falling through summer ($35\cdot09\text{‰}$) to a minimum in autumn ($35\cdot04\text{‰}$), rising again in winter to $35\cdot11\text{‰}$. In all seasons in both years the gradient of the surface salinity was from high in the west to low in the east. In Plate VII the hatched area in the diagram for spring shows that in this season surface water of higher salinity than $35\cdot40\text{‰}$ occupied a greater area in 1951-52 than in 1950-51, although the corresponding area was warmer in 1950-51 than in 1951-52. In summer the surface water in 1951-52 was everywhere of greater salinity than in 1950-51, the $35\cdot40\text{‰}$ isohaline not appearing anywhere in the summer of 1950-51. In autumn, surface water of salinity greater than $35\cdot40\text{‰}$ was restricted to the western edge of the area in 1950-51, whereas in 1951-52 its presence was seen in the south-west corner of the area and its influence was felt along the southern edge. In winter, the $35\cdot40\text{‰}$ isohaline was absent in 1951-52 whereas in 1950-51, it was present along the whole western edge. The low surface salinity at Station P off Stompneus in the winter of 1950-51 is undoubtedly due to dilution by the rain-freshened Berg River.

The main differences in the seasonal variation of surface salinities in the two years are the increased area of salinity greater than $35\cdot40\text{‰}$ in the spring of 1951-52, particularly along the southern edge of the area, the absence of such water in the summer of 1950-51 compared with high salinities in the summer of 1951-52 along the southern edge, the influence of high salinity water along the southern edge in autumn 1951-52 and the absence of water of $35\cdot40\text{‰}$ in winter 1951-52.

Plate VIII shows the seasonal variation of the phosphate-content of the sea surface in the routine area in the two years. The hatched areas show the regions where the phosphate-content was greater than $0\cdot60$ mg-atoms P/m^3 . Throughout all seasons in both years phosphate was always highest at the coastal stations, particularly off Lambert's Bay, and lowest to the west, the gradient usually rising steadily from the west until the coast is neared when the phosphate-content increased very considerably. In 1950-51 the mean surface value of phosphate-content for the routine area increased throughout the year from a minimum in spring ($0\cdot53$ mg-atoms P/m^3) through summer ($0\cdot64$) and autumn ($0\cdot68$) to a maximum in winter ($0\cdot75$), whereas in 1951-52 the mean surface phosphate value fell from a maximum in spring ($0\cdot65$) through summer ($0\cdot55$) to a minimum in autumn ($0\cdot52$) to rise again in winter ($0\cdot64$). The reason for the striking feature of the continued rise of phosphate in the sea surface in 1950-51 is not at present understood.

In the spring of 1950-51 the surface phosphate was everywhere fairly uniform (*circa* $0\cdot50$) except near Lambert's Bay where it was higher ($0\cdot73$), whilst in the same season in 1951-52 the surface phosphate was universally higher ($0\cdot47$ - $0\cdot95$). In summer in 1950-51 the eastern side of the routine area had a greatly increased phosphate-content in the surface ($0\cdot60$ - $1\cdot34$) compared with spring ($0\cdot46$ - $0\cdot73$) in the same year, particularly near Stompneus ($1\cdot34$) and off Saldanha Bay ($0\cdot90$). A body of water of lower phosphate-content ($0\cdot40$ - $0\cdot50$) was present in the south-west in the summer of 1950-51. The phosphate-content in the summer of 1951-52 in the western half of the area ($< 0\cdot40$) and along the southern edge ($0\cdot34$ - $0\cdot45$) was considerably lower than in the same season in 1950-51. Maximum phosphate was found off Lambert's Bay ($1\cdot43$) in summer 1951-52. The smaller amount of phosphate, particularly along the southern edge and to the west, which was first noticed in the summer of 1951-52, was again seen in both autumn and winter in 1951-52. Thus the southern edge of the area had a content of

0.30–0.45 mg-atoms P/m³ in autumn 1951–52 compared with 0.51–0.94 in autumn 1950–51 and of 0.41–0.55 in winter 1951–52 compared with 0.63–0.94 in the winter of 1950–51. In contrast to the smaller quantity of phosphate in the west and along the southern edge in autumn and winter of 1951–52, the content at Lambert's Bay was very high in these two seasons of 1951–52 (1.60 in autumn and 1.20 in winter).

The seasonal differences in the temperature, salinity and phosphate-content of the surface of the sea can perhaps best be seen in Plates IX to XI, which represent the seasonal values at individual stations in 1950–51 minus those for 1951–52. When the sign is negative in front of a value it indicates that the seasonal average in 1951–52 was greater than in 1950–51, an occurrence which is also marked by hatching of the areas in which this took place. The seasonal differences in the surface may be summarized as follows: In spring, 1950–51 was warmer nearly everywhere, was mainly less saline, particularly at Station H on the southern line, and was nearly everywhere of lower phosphate-content. In summer, 1950–51 was cooler everywhere except most of St. Helena Bay, and particularly cooler along the southern edge, was less saline, particularly along the southern edge and to the north-west, and was of higher phosphate-content except in the north of St. Helena Bay and off Cape Columbine, being particularly higher in phosphate along the southern edge. In autumn, 1950–51 was particularly warmer to the north-east and south-west, and particularly colder along the southern edge and to the north-west, was more saline to the west and less saline to the east and south, particularly along the middle of the southern line, was of higher phosphate content except off Lambert's Bay and Cape Columbine, being particularly higher along the southern line. In winter, 1950–51 was warmer to the north-east and the west but cooler to the north and south, St. Helena Bay being markedly warmer, was more saline to the north-east and west but less saline elsewhere, particularly less saline at Stations Q and H, and was of higher phosphate-content everywhere except off Lambert's Bay and Cape Columbine, being particularly higher along the southern edge. In general a seasonal increase in temperature is associated with a fall of phosphate and an increase in salinity.

From a consideration of the above summary it is evident that there are three areas where the largest seasonal differences of T°, S₀₀° and P occur. These areas are (1) the south-west of the routine

area, (2) off Lambert's Bay and (3) along the southern edge of the routine area.

Plate XII shows the seasonal variation of the mean integral temperature in the 0–50 metres layer, the 15°C. isotherm being thickened and the area > 15°C. being shown by hatching. In 1950–51, taking the whole routine area into consideration, the mean integral value of temperature in the 0–50 metres layer fell from 14.37°C. in spring to a minimum of 13.95°C. in summer, to rise to a maximum of 14.61°C. in autumn and to fall to 14.36°C. in winter. The mean integral temperature of the same layer in 1951–52 differed from the previous year in that the value for the whole routine area rose from a minimum of 13.78°C. in spring to a maximum of 14.86°C. in summer, to fall to 14.02°C. in autumn and to rise to 14.07°C. in winter. In all seasons in both years the temperature gradient in the 0–50 metres layer was from high seawards to low towards the coast.

In the spring of 1950–51 at the great majority of stations, the 0–50 metres layer was warmer than in 1951–52; this is in agreement with the values in the surface. In summer in 1951–52 the 0–50 metres layer was considerably warmer than in 1950–51, particularly over the western side of the routine area and along the southern edge. Thus at Station A in 1951–52 the 0–50 metres layer was 2.24°C. warmer than in 1950–51 and at Station R near Saldanha Bay 1.31°C. warmer; again this is in agreement with the surface values. In the autumn of 1951–52 the 0–50 metres layer was colder than in 1950–51, the chief differences being the presence of warmer water to the west in 1950–51 and colder water close to Lambert's Bay in 1951–52, although the thrust of warmer water along the southern edge of the area in 1951–52 which was noticed in the surface, was again present in the 0–50 metres layer. In winter the 0–50 metres layer was again warmer in 1950–51 than in 1951–52, the chief differences being the presence of warmer water in the south-west in 1950–51 and of cooler water in 1951–52 in St. Helena Bay.

The outstanding differences in the seasonal variation of temperature in the 0–50 metres layer in the two years are the higher temperatures nearly everywhere in the spring of 1950–51, the warmer water of 1951–52 in summer, particularly along the western edge and the southern edge of the routine area, the presence in autumn in 1950–51 of warmer water to the west, the continued thrust of warmer water along the southern edge in 1951–52, and the lower temperature at Lambert's Bay in

autumn 1951-52 and the lower temperatures throughout St. Helena Bay in the winter of 1951-52.

Plate XIII shows the seasonal variation of salinity in the 0-50 metres layer in the two years, the 35.40‰ isohaline being thickened and the area of salinity greater than 35.40‰ being hatched. In 1950-51 the mean salinity of the 0-50 metres layer in the whole area fell from a value of 35.14‰ in spring to a minimum of 34.98‰ in summer, to rise in autumn to 35.04‰ and a maximum of 35.15‰ in winter. In 1951-52 the mean salinity of the 0-50 metres layer rose to a maximum of 35.19‰ in spring, falling to 35.11‰ in summer and a minimum of 35.02‰ in autumn, followed by a rise to 35.10‰ in winter. In all seasons of both years the gradient of salinity in this layer was from high seawards to low at the coast.

The hatched area in Plate XIII shows that in spring water of mean integral salinity greater than 35.40‰ in the 0-50 metres layer occupied a greater area in 1951-52 than in 1950-51, although in this area the temperature of the layer was higher in 1950-51. In summer the mean integral salinity of the 0-50 metres layer in 1951-52 was everywhere higher than in 1950-51, the 35.40‰ isohaline not appearing anywhere in the area in 1950-51. In autumn the presence of water of greater salinity than 35.4‰ in the 0-50 metres layer is seen in the western edge of the routine area in 1950-51, whilst in 1951-52 its presence is seen in the south-west corner of the area and its influence may be seen along the southern edge in that year. In winter the 35.4‰ isohaline was absent in 1951-52, whereas in 1950-51 it was present in the western edge of the area.

The main differences in the seasonal variation of salinity in the 0-50 metres layer in the two years are the larger area in the spring of 1951-52 in which the mean integral value of salinity was greater than 35.4‰, particularly along the southern edge of the area, the higher salinity everywhere in summer in 1951-52, particularly along the western and southern edges of the area, the continued influence of higher salinity water

along the southern edge in the autumn of 1951-52, and the lower salinity nearly everywhere in winter in 1951-52.

Plate XIV shows the seasonal variation of the phosphate-content in the 0-50 metres layer in the routine area in the two years. The 0.70 mg-atoms P/m³ line is thickened in the diagrams and the area where the phosphate-content is greater than 0.70 mg-atoms P/m³ has been hatched. In both years in all seasons phosphate is always highest at the coast particularly off Lambert's Bay, and lowest to the west, the gradient usually rising steadily from the west until the coast is reached where the increase is very considerable. In 1950-51 the mean phosphate of the 0-50 metres layer rose from a value of 0.79 mg-atoms P/m³ in spring through summer (0.95) to a maximum in autumn of 1.03, after which it fell to a value of 0.95 in winter. In 1951-52 the mean phosphate for this layer fell from a value of 0.92 in spring to a minimum of 0.84 in summer, rising to a maximum of 0.97 in autumn and to fall again in winter to 0.88.

In the spring of 1950-51 the mean integral phosphate in the 0-50 metres layer was fairly uniform (0.6-0.7) in the western half of the area, but increased rapidly towards the coast particularly in St. Helena Bay, (1.3-1.6), whereas in the same season in 1951-52 phosphate was higher nearly everywhere, but the gradient shorewards was lessened. In summer the western side of the area had a lower phosphate-content in this layer in 1951-52 (0.5-0.7) than in 1950-51 (0.6-0.9) but at Lambert's Bay in 1951-52 the mean integral value was as high as 1.88 compared with 1.50 in 1950-51. The southern edge of the routine area had a lower phosphate-content in the upper 50 metres in 1951-52 than in 1950-51. The lowered phosphate in the western half of the area and along the southern edge in 1951-52, which was first seen in summer, occurred again in both autumn and winter. Thus the western half of the routine area had a phosphate-content of 0.4-1.0 in autumn 1951-52 compared with 0.65-1.3 in autumn 1950-51 and of 0.5-1.1 in winter 1951-52 compared with 0.6-1.1 in winter 1950-51. In contrast to these declines in autumn and winter 1951-52

the content at Lambert's Bay in these seasons in 1951-52 was very high (2.03 in autumn and 1.67 in winter).

The seasonal differences in the temperature, salinity and phosphate-content in the 0-50 metres layer can best be seen in Plates XV to XVII which represent the seasonal values at individual stations in 1950-51, minus those for 1951-52. When the sign is negative in front of a value it indicates that the seasonal average in 1951-52 was greater than in 1950-51, an occurrence which is also marked by hatching of the area in which this occurred. The seasonal differences in the two years in the 0-50 metres layer agree very closely with those in the surface and may be summarized as follows: In spring the 0-50 metres layer in the routine area was warmer nearly everywhere in 1950-51 particularly from south-west to north-east but with a colder patch at Station H, was in general less saline, particularly at Station H in the same year, and was of lower phosphate-content particularly from south-west to north-east but with a larger amount of phosphate off Lambert's Bay and Saldanha Bay in 1950-51. In summer the 0-50 metres layer in 1950-51 was much colder except off St. Helena Bay, was much less saline and was of higher phosphate-content except at Lambert's Bay, where in 1951-52 the content was considerably higher. The southern edge of the routine area was the site where particularly colder, less saline and higher phosphate water was found in 1950-51 than in 1951-52. In autumn the 0-50 metres layer in 1950-51 was warmer from the south-west to north-east, was more saline in the west but less saline in the east, and was of higher phosphate-content in the south-west but less inshore. At Stations G and H along the southern edge of the routine area the 0-50 metres layer was markedly cooler, less saline and of higher phosphate-content in 1950-51 than in 1951-52. In winter the 0-50 metres layer in 1950-51 was warmer than in 1951-52 except along the southern edge, was more saline except at Stations H, G, O and Q, and had a higher phosphate-content except off Lambert's Bay, Stompneus and Cape Columbine. The southern edge was again colder, less saline and of higher phosphate-content in 1950-51 than in 1951-52.

It is again evident from a consideration of the differences in the seasonal averages of the 0-50 metres layer that three positions in the routine area stand out as places where greatest seasonal changes occurred. These positions are (1) the south-west of the routine area, (2) off Lambert's Bay and (3) along the southern edge particularly at Stations G and H.

8. RANGE OF SURFACE TEMPERATURE, SALINITY AND INORGANIC PHOSPHATE-CONTENT IN THE ROUTINE AREA.

In 1950-51 the range of temperature, salinity and inorganic phosphate-content in the surface of the sea in the routine area was from 12.22° to 20.21°C., 34.22‰ to 35.59‰ S., and 0.64 to 2.03 mg-atoms P/m³. In 1951-52 the corresponding ranges were 11.79° to 21.51°C., 34.45‰ to 35.62‰ S. and 0.63 to 2.37 mg-atoms P/m³.

In winter the Berg River in St. Helena Bay becomes swollen by the addition of rain-water. This has the effect of diluting the surface water at Station P which is close by and in so doing, increases the range of surface salinity by diminishing the salinity at the lower end of the range.

Maximum temperature at each of the routine stations did not occur in the same month in either 1950-51 or 1951-52. In 1950-51 maximum temperature occurred on 50 per cent of occasions in May and 15 per cent in April and October, whilst in 1951-52 it occurred on 55 per cent of occasions in January and 30 per cent in February. Thus maximum temperature in the sea surface was found chiefly in autumn in 1950-51 and in summer in 1951-52 but never in winter in either year.

Similarly minimum surface temperature was found to occur in several months of the year at different places within the routine area. In 1950-51 minima occurred on 55 per cent of occasions in August, 25 per cent in February and 10 per cent in March whilst in 1951-52 minima occurred on 17½ per cent of occasions in August and October,

and 15 per cent in May, September and December. Thus minimum temperature in the surface was found chiefly in late winter in 1950-51 but also to a lesser degree in late summer and early autumn, whilst in 1951-52 its occurrence was more spread out in season covering late winter and mid-spring and to a lesser degree late autumn, early spring and early summer. It is obvious that data from subsequent years are needed to give more accurately the season in which minimum temperature in the surface may be expected.

Maximum surface salinity was also found to occur in several months of the year but principally as follows: In 1950-51 maxima occurred on 52½ per cent of occasions in August to September and on 30 per cent of occasions in April to May. In 1951-52 maxima occurred on 25 per cent of occasions in January, 20 per cent in September, 15 per cent in October and December. Thus in 1950-51 maximum salinity in the surface occurred chiefly in late winter to early spring and to a lesser degree in autumn, whereas in 1951-52 its occurrence tended to be more spread out over spring and summer.

Minimum surface salinity in 1950-51 was chiefly confined to the months of January (20 per cent), February (25 per cent), March (10 per cent), April (20 per cent) and June (20 per cent), whereas in 1951-52 it occurred in December (7½ per cent), January (10 per cent), February (34 per cent), March (10 per cent), April (17½ per cent) and May (10 per cent). Thus in 1950-51 minimum surface salinity tended to occur in the period January to June or mid-summer, autumn and early winter, whilst in 1951-52 it occurred in summer and autumn. Minima tended to be absent in winter in both years.

In 1950-51 maximum surface inorganic phosphate occurred during several months but chiefly in February (15 per cent), March (20 per cent), June (17½ per cent) and August (25 per cent), whereas in 1951-52 it occurred principally in September (20 per cent) and October (30 per cent). Thus in 1950-51 it tended to occur in late summer, early autumn and winter, whilst in 1951-52 spring

was the chief season for maximum phosphate in the sea surface.

Minimum surface inorganic phosphate in 1950-51 occurred chiefly in December (50 per cent), but in the period November to February its frequency of occurrence was 95 per cent, whereas in 1951-52 it occurred most frequently in February (32½ per cent), but in the period November to April its frequency was 100 per cent. In 1950-51 minimum phosphate did not occur in autumn and winter whilst in 1951-52 it was absent in late autumn, winter, and, early- and mid-spring. Thus in the surface, minimum phosphate tended to occur in late spring to late summer in 1950-51 and in late spring to mid-autumn in 1951-52.

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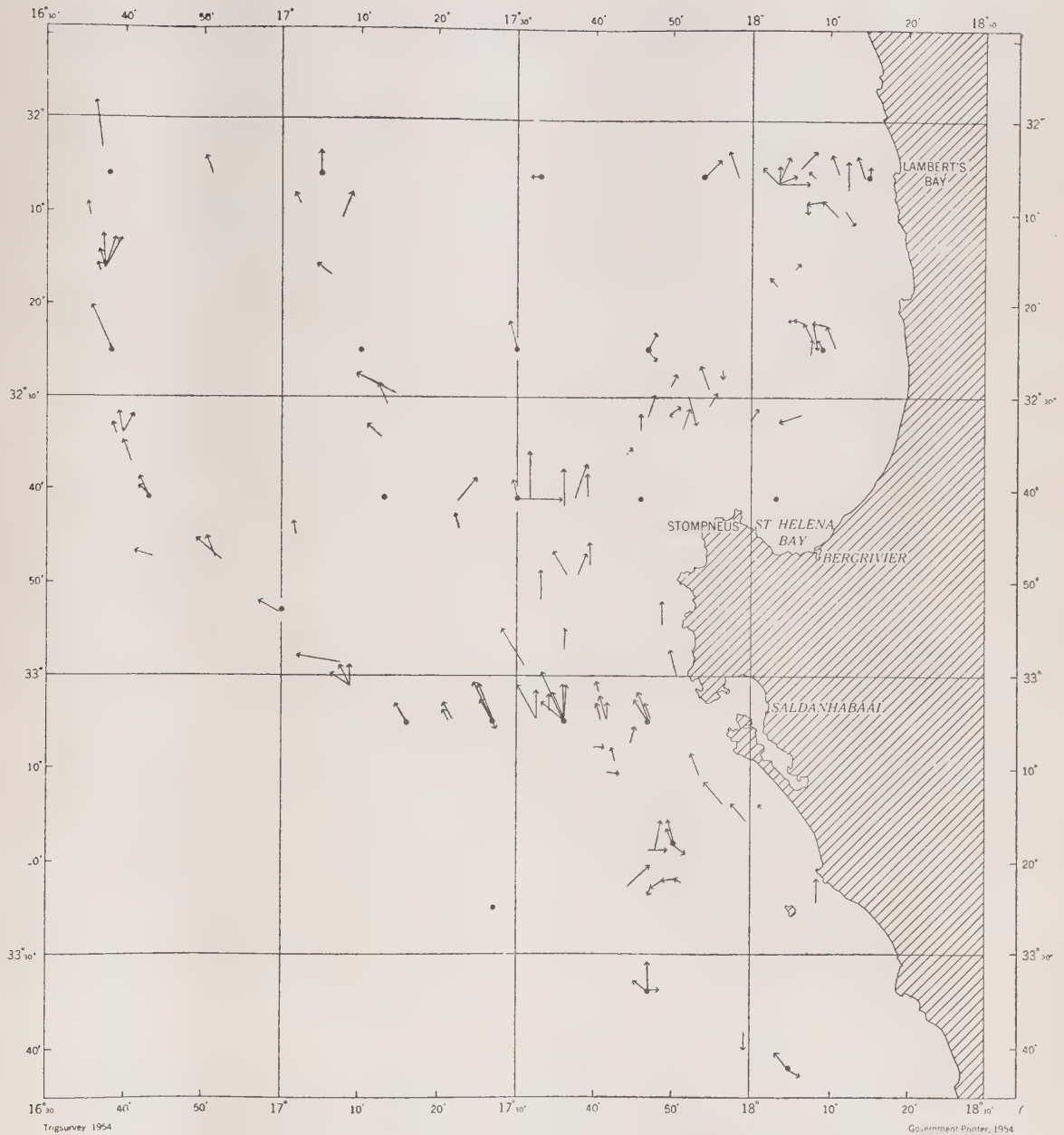


PLATE I SURFACE CURRENTS FROM NAVIGATIONAL DATA OCTOBER 1950 OCTOBER 1953 IN ROUTINE AREA

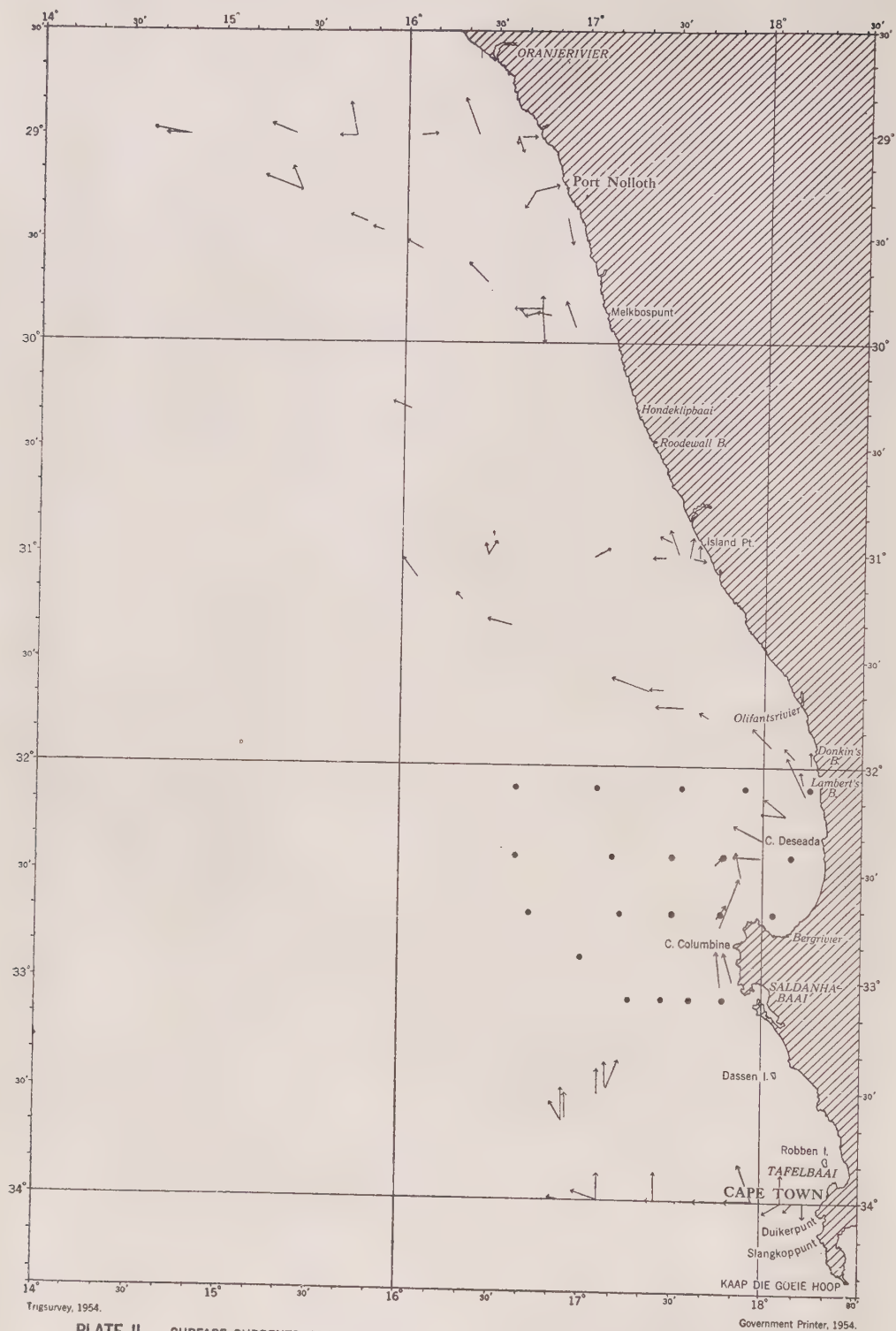


PLATE II SURFACE CURRENTS FROM NAVIGATIONAL DATA NOVEMBER 1951-MARCH 1953 IN SEARCH AREA.

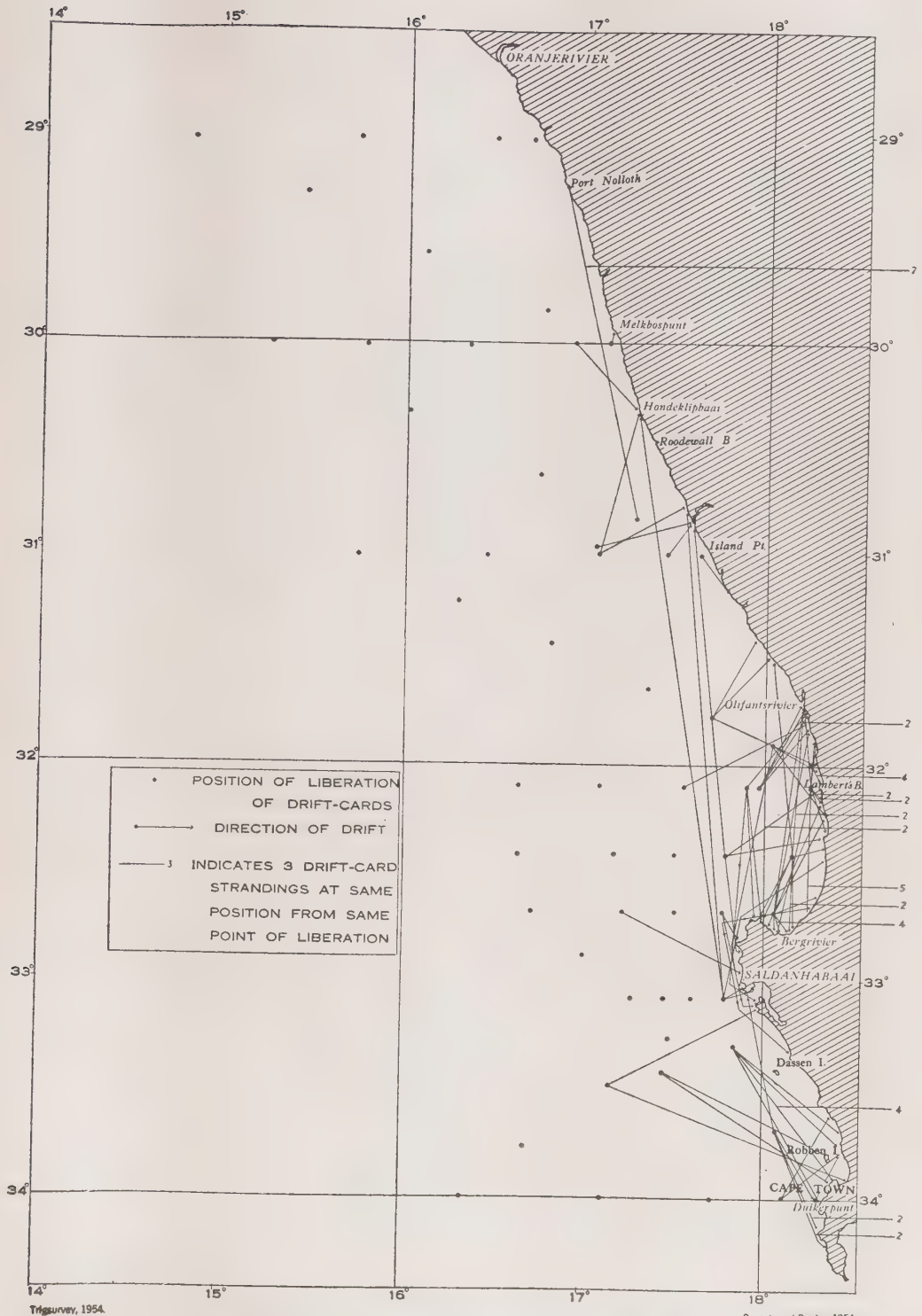
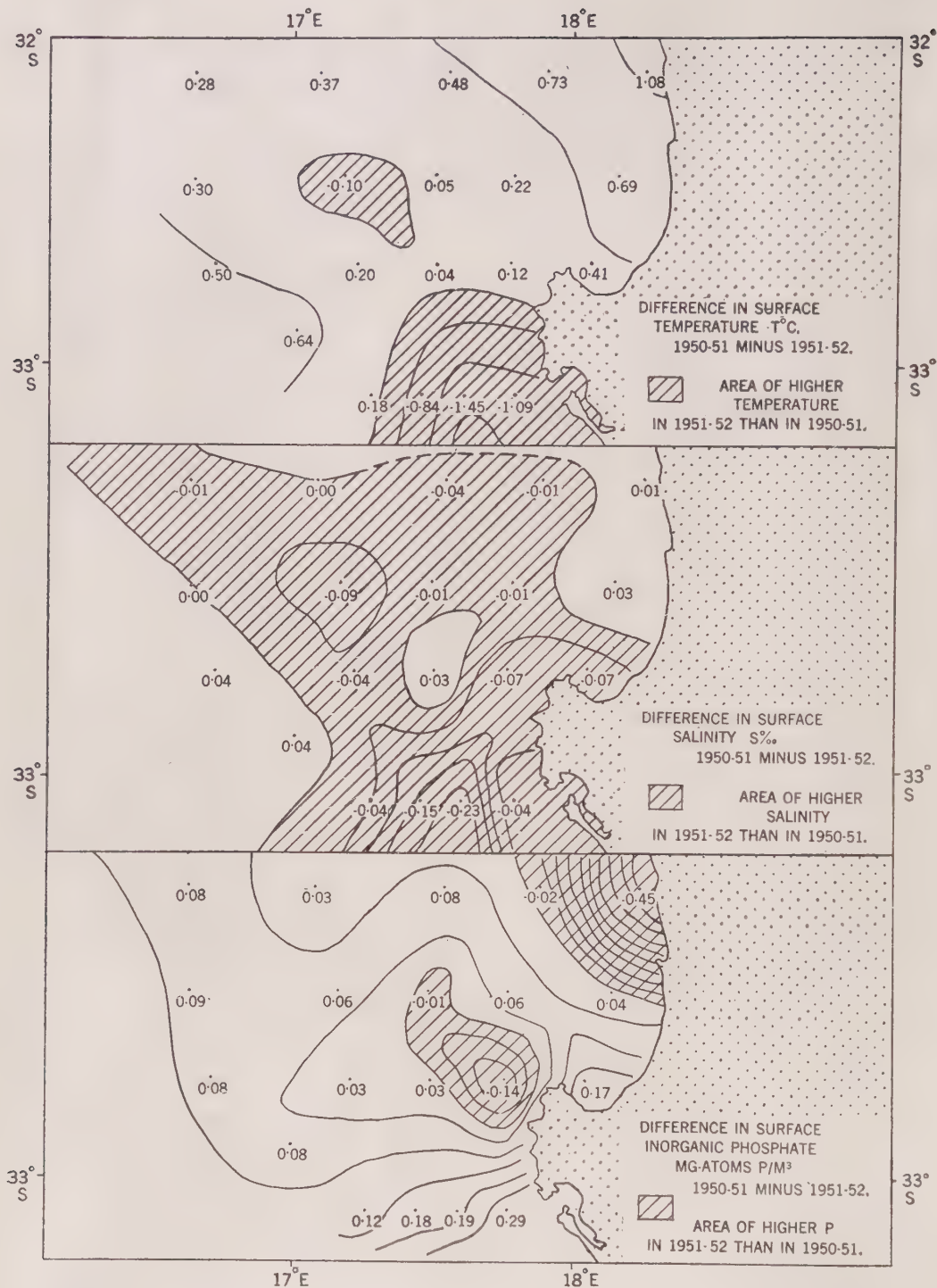


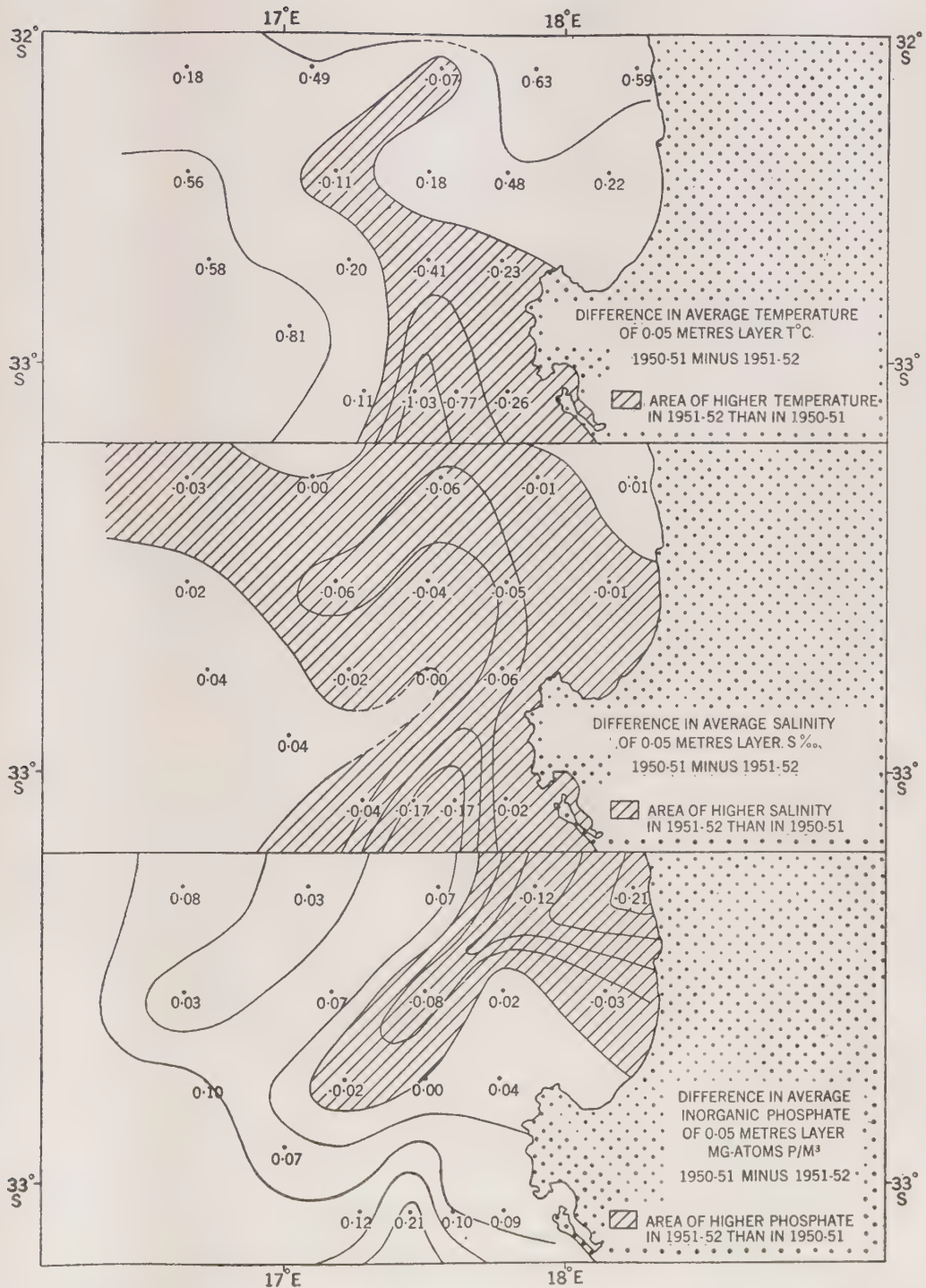
PLATE III MOVEMENT OF DRIFT CARDS NOVEMBER 1952 - OCTOBER 1953.



Trigsurvey, 1954.

Government Printer, 1954.

PLATE IV DIFFERENCE IN SURFACE TEMPERATURE, SALINITY AND INORGANIC PHOSPHATE IN 1950-51 AND 1951-52



Trigsurvey, 1954.

Government Printer, 1954.

PLATE V DIFFERENCE IN AVERAGE TEMPERATURE, SALINITY AND INORGANIC PHOSPHATE OF 0.50 METRE LAYER IN 1950-51 AND 1951-52

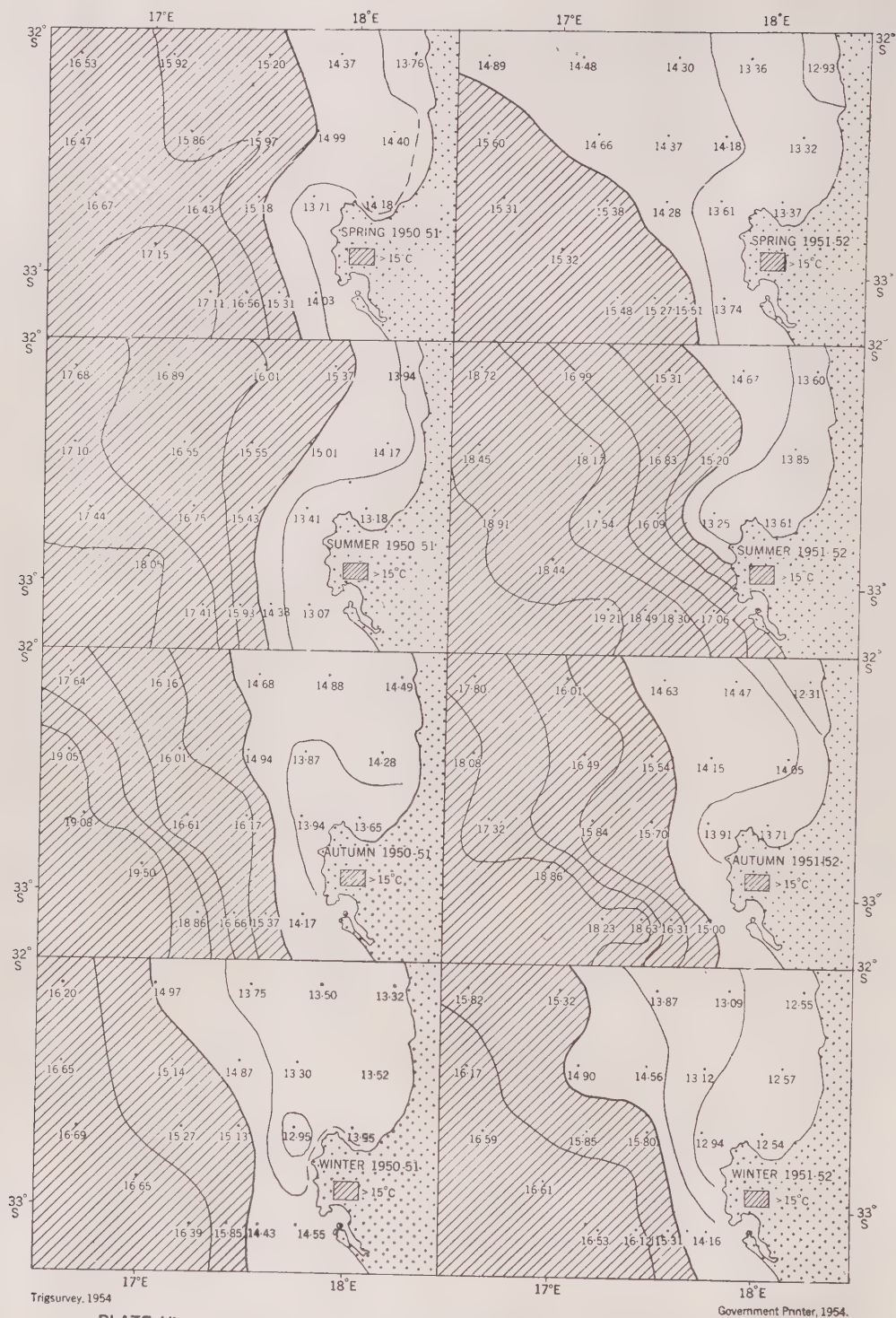


PLATE VI SEASONAL VARIATION OF SURFACE TEMPERATURE. 1950-51 AND 1951-52.

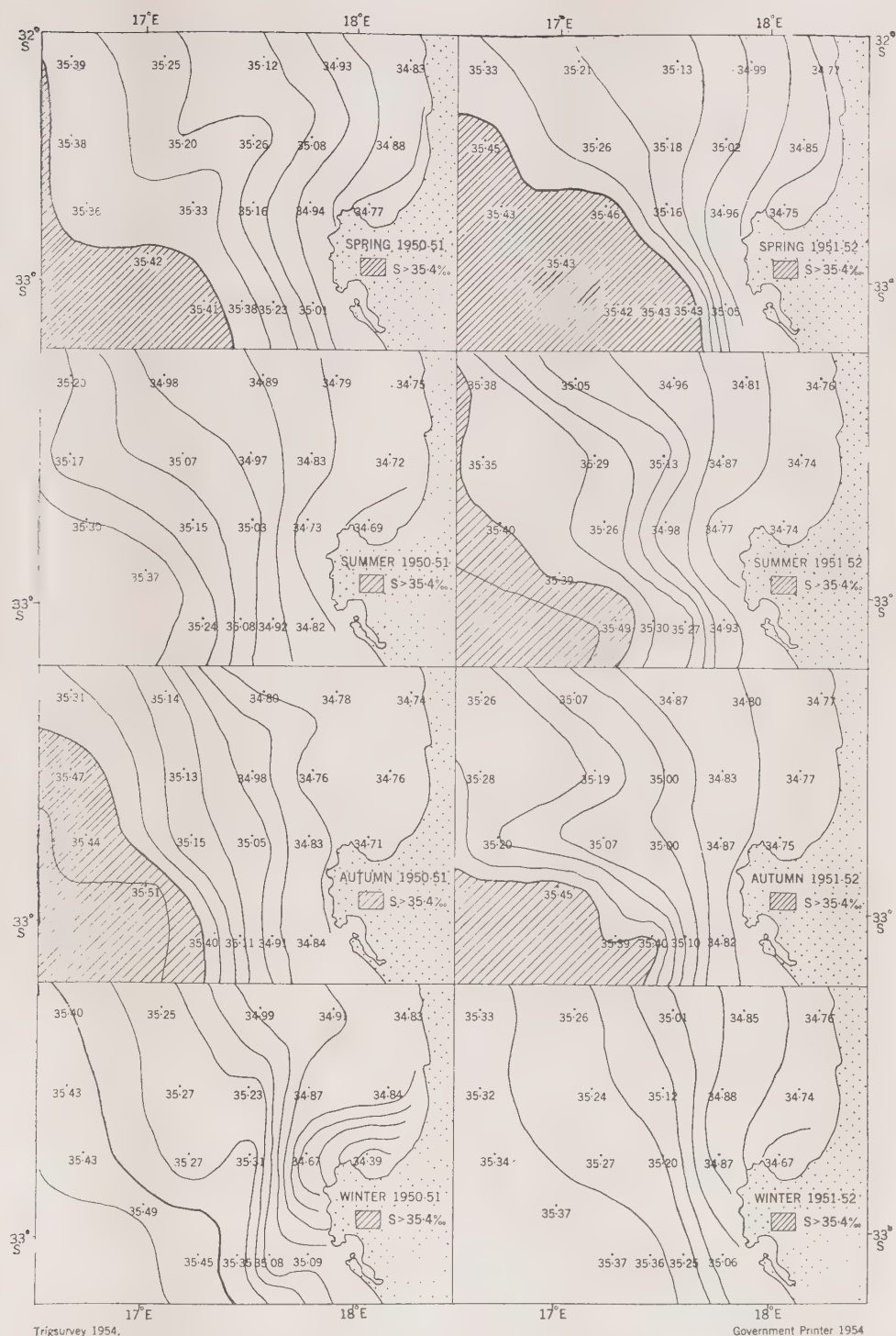


PLATE VII SEASONAL VARIATION OF SURFACE SALINITY 1950-51 AND 1951-52.

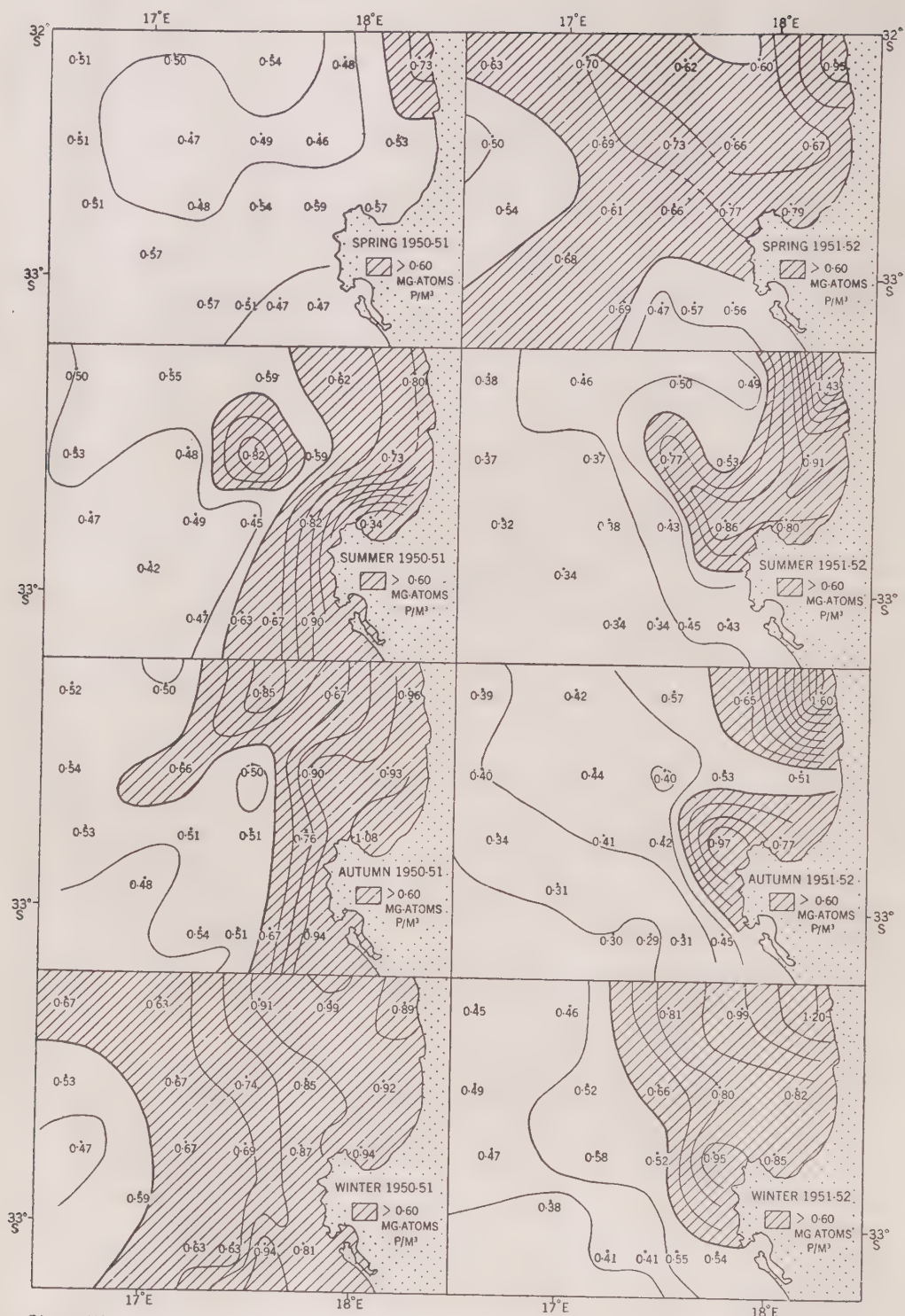


PLATE VIII SEASONAL VARIATION OF SURFACE INORGANIC PHOSPHATE IN 1950-51 AND 1951-52

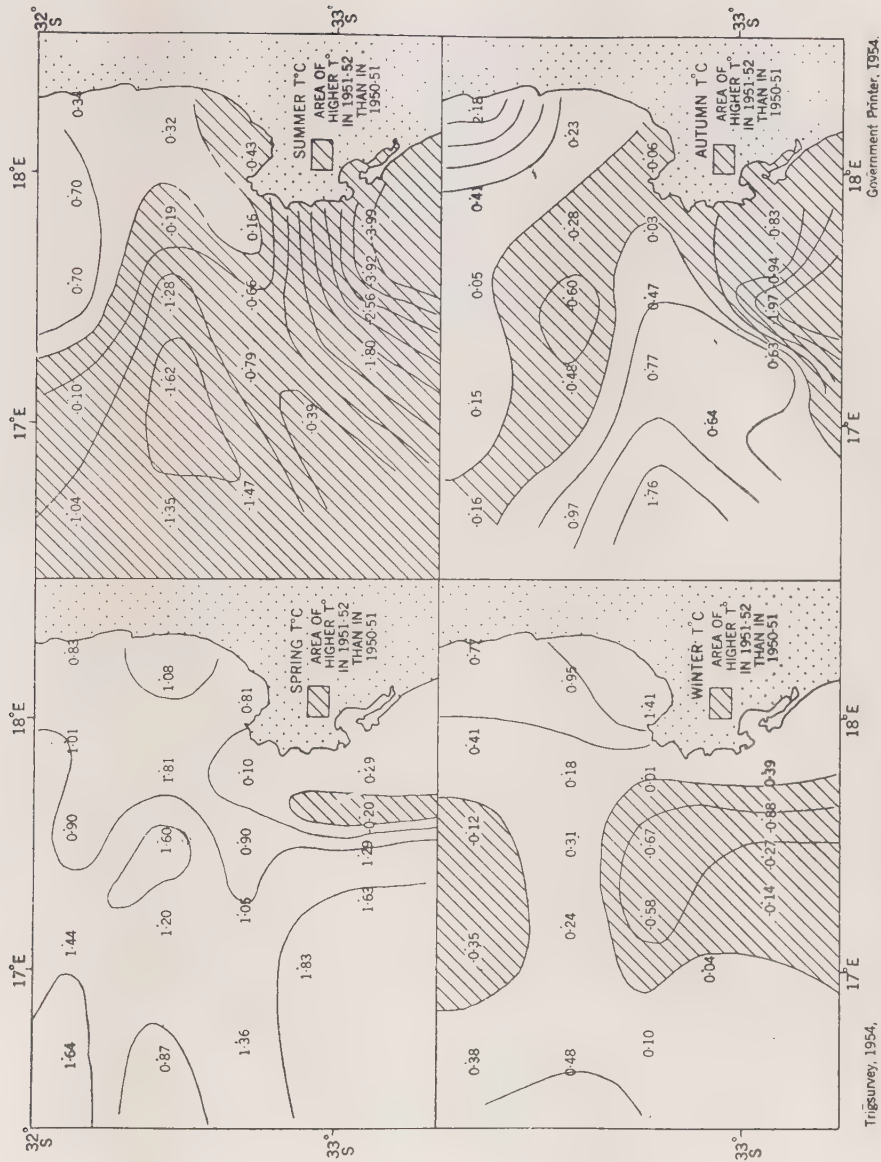
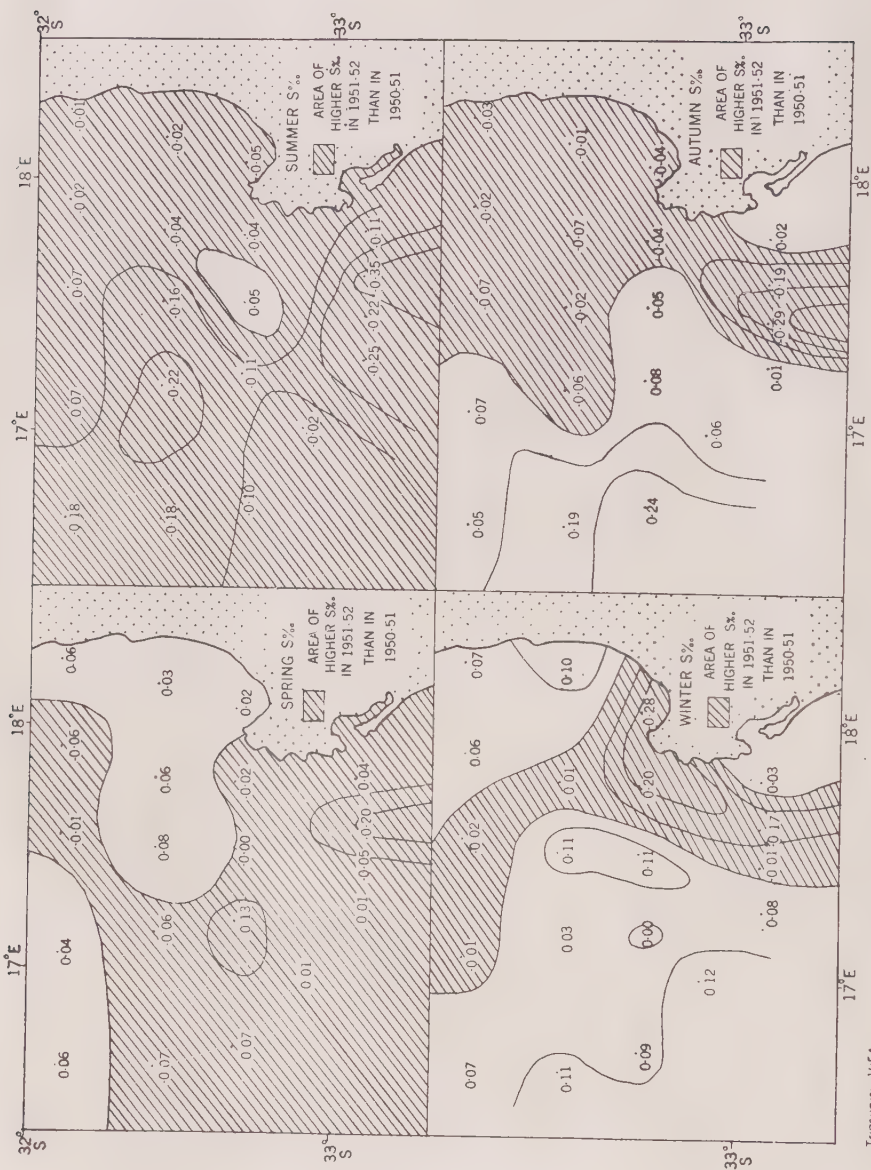


PLATE IX SEASONAL DIFFERENCES IN SURFACE TEMPERATURE IN 1950-51 AND 1951-52.

Government Printer, 1954.



Trigsurvey, 1954

Government Printer, 1954.

PLATE X SEASONAL DIFFERENCES IN SURFACE SALINITY IN 1950-51 AND 1951-52.

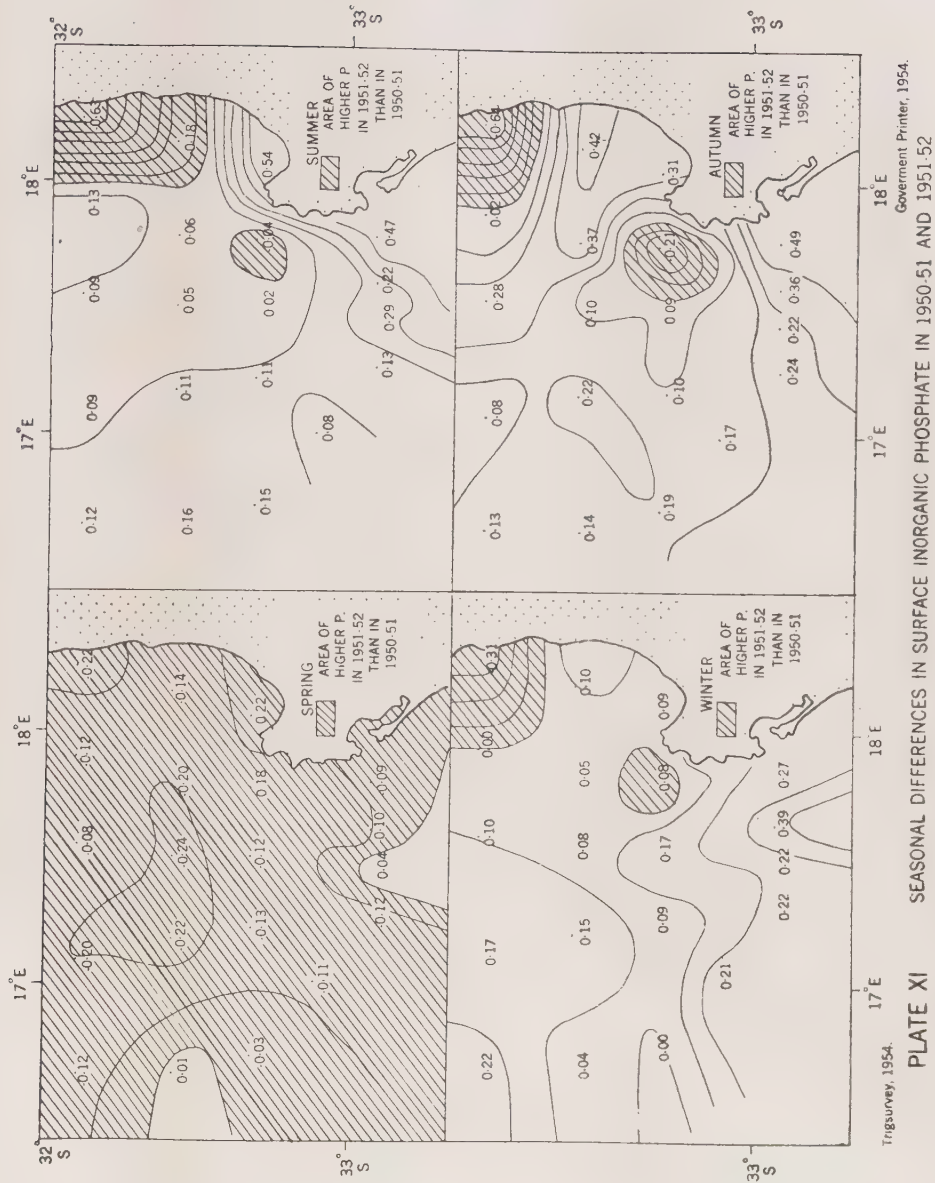


PLATE XI SEASONAL DIFFERENCES IN SURFACE INORGANIC PHOSPHATE IN 1950-51 AND 1951-52

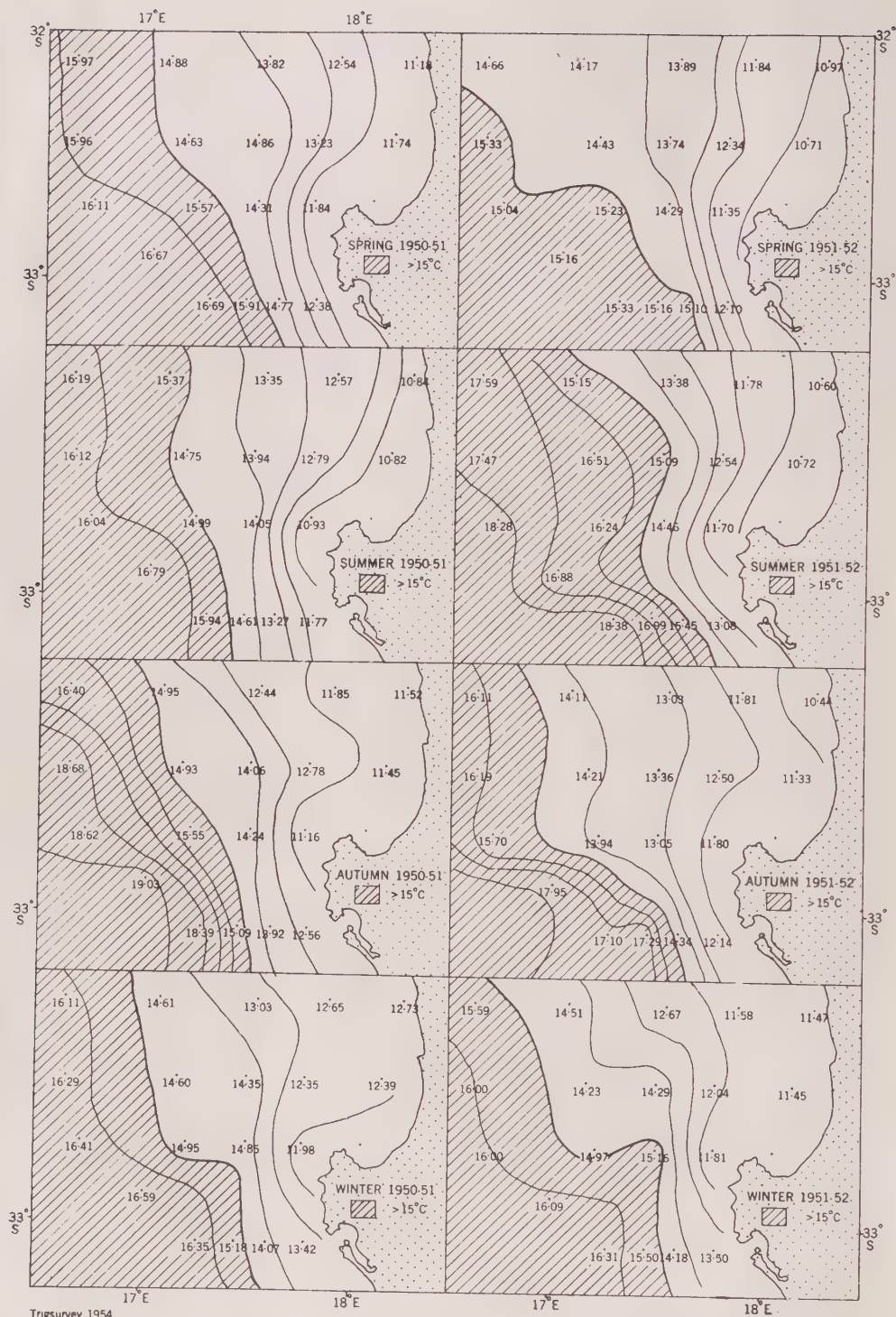


PLATE XII SEASONAL VARIATION OF TEMPERATURE IN 0-50 M. LAYER 1950-51 AND 1951-52.

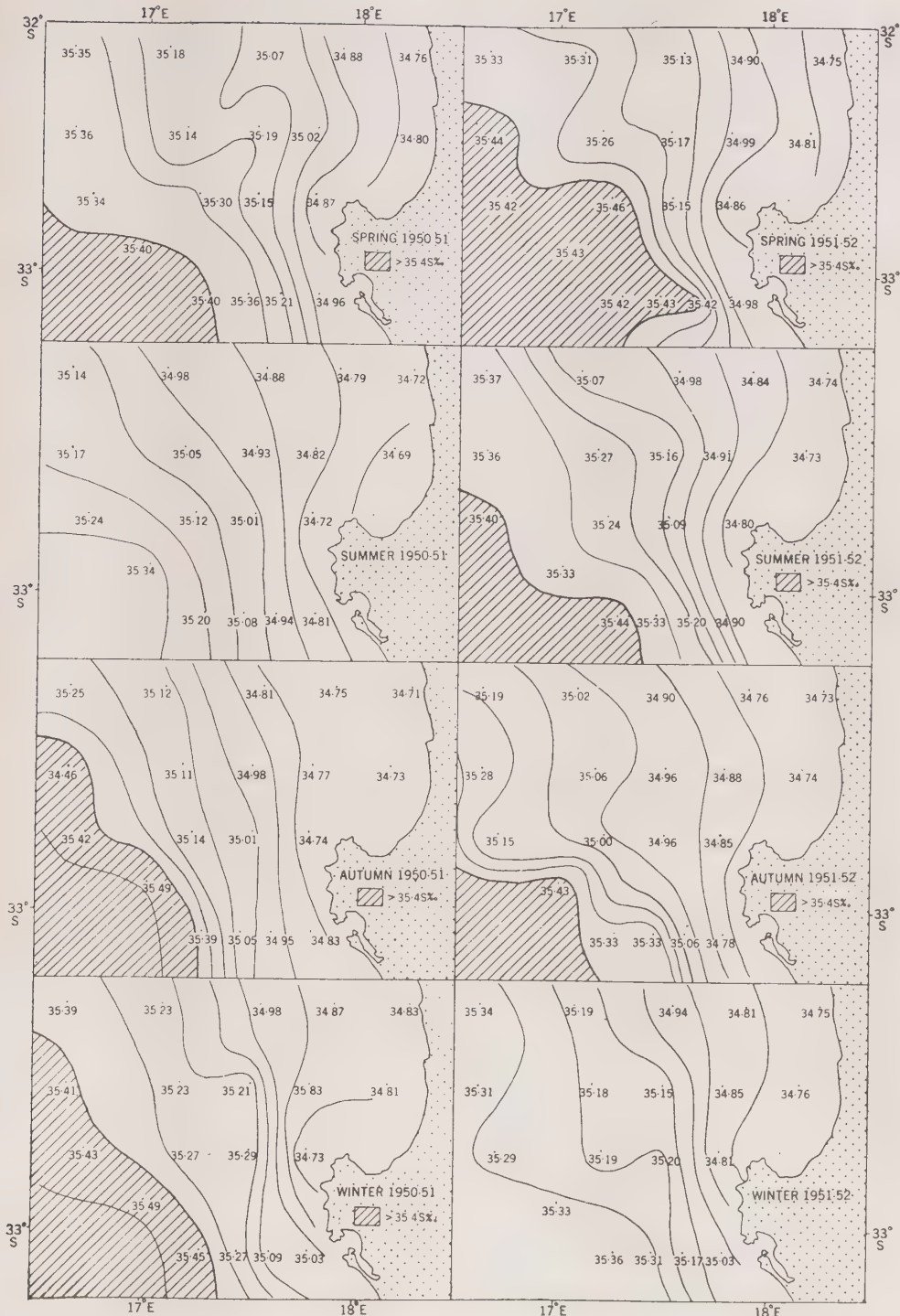
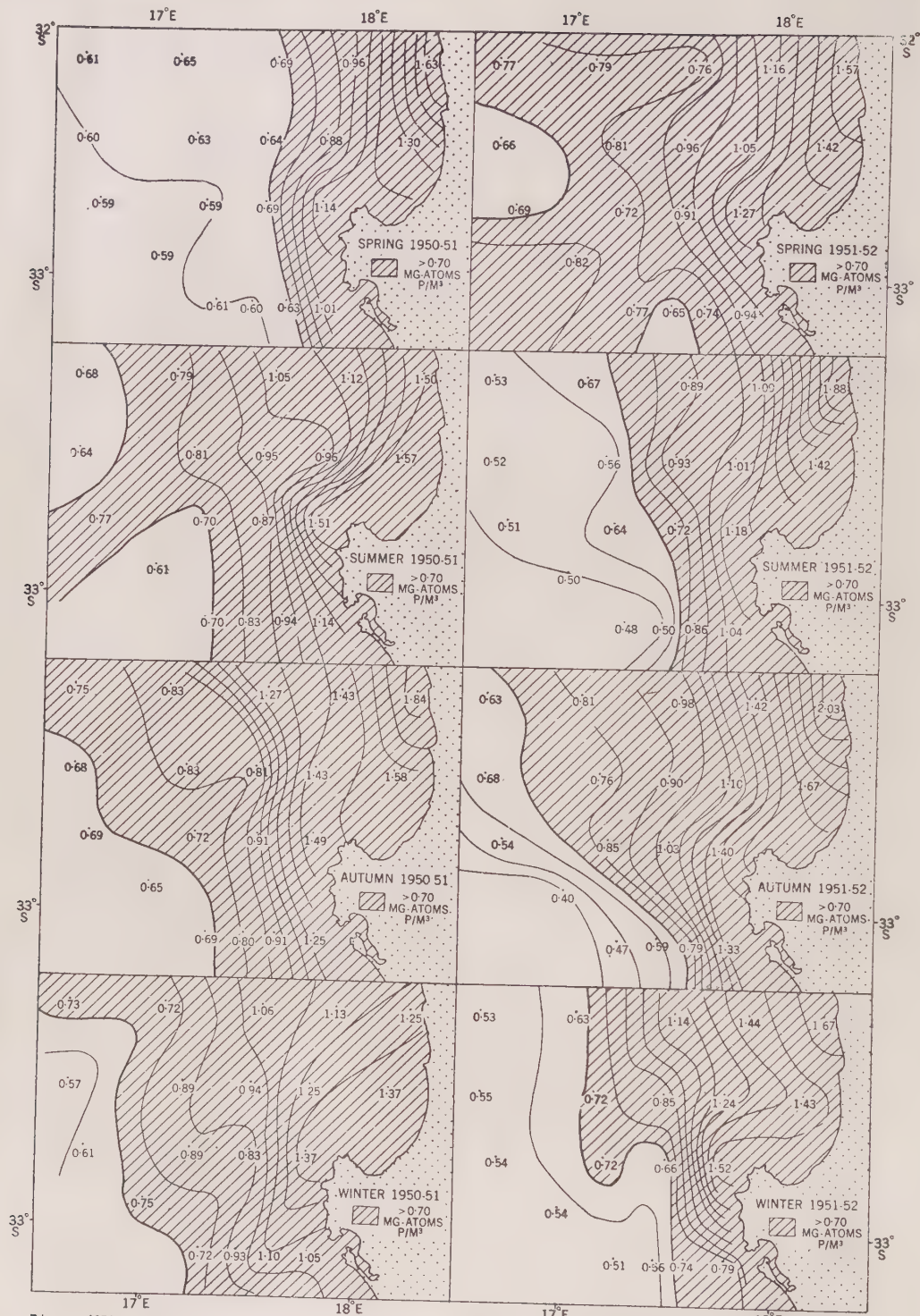


PLATE XIII SEASONAL VARIATION OF SALINITY IN THE 0-50m. LAYER 1950-51 AND 1951-52



Trigsurvey 1954.

PLATE XIV

SEASONAL VARIATION OF INORGANIC PHOSPHATE IN 0.50 M. LAYER IN 1950-51 AND 1951-52.

Government Printer 1954.

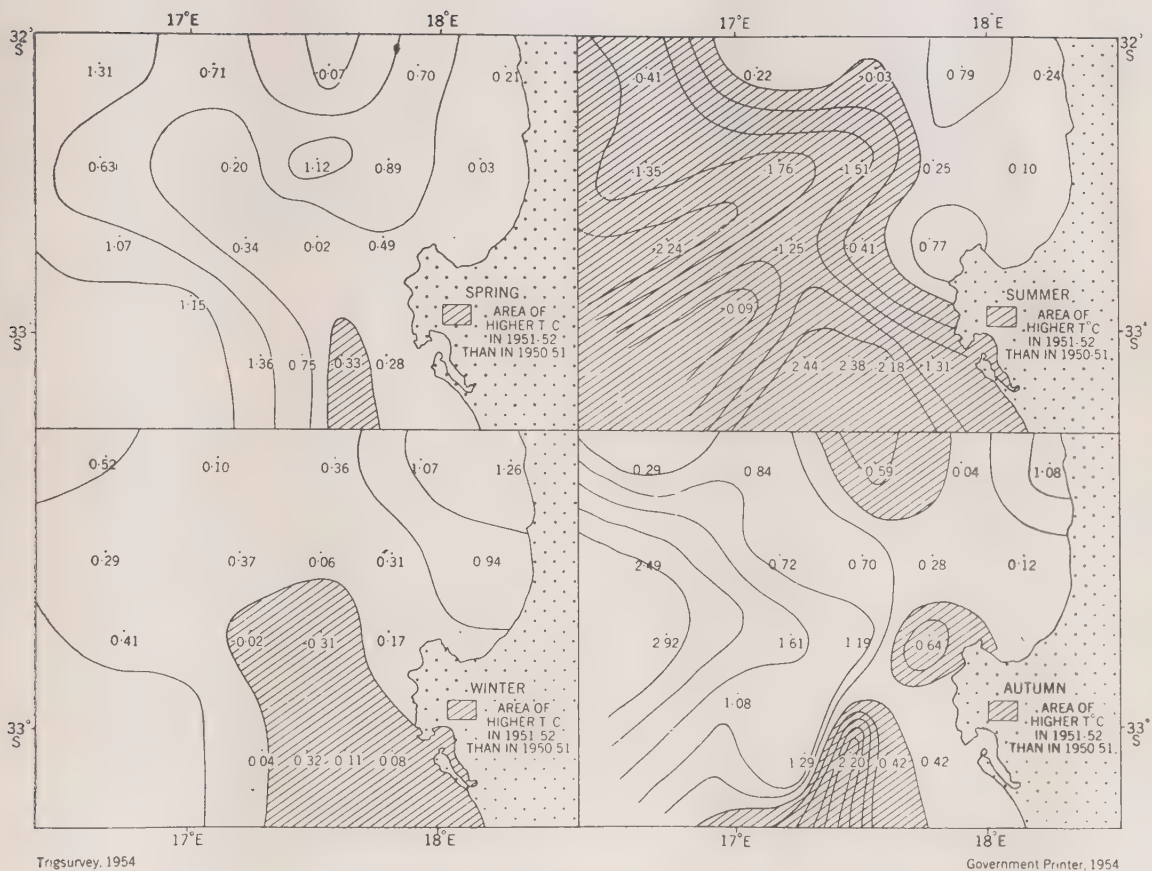
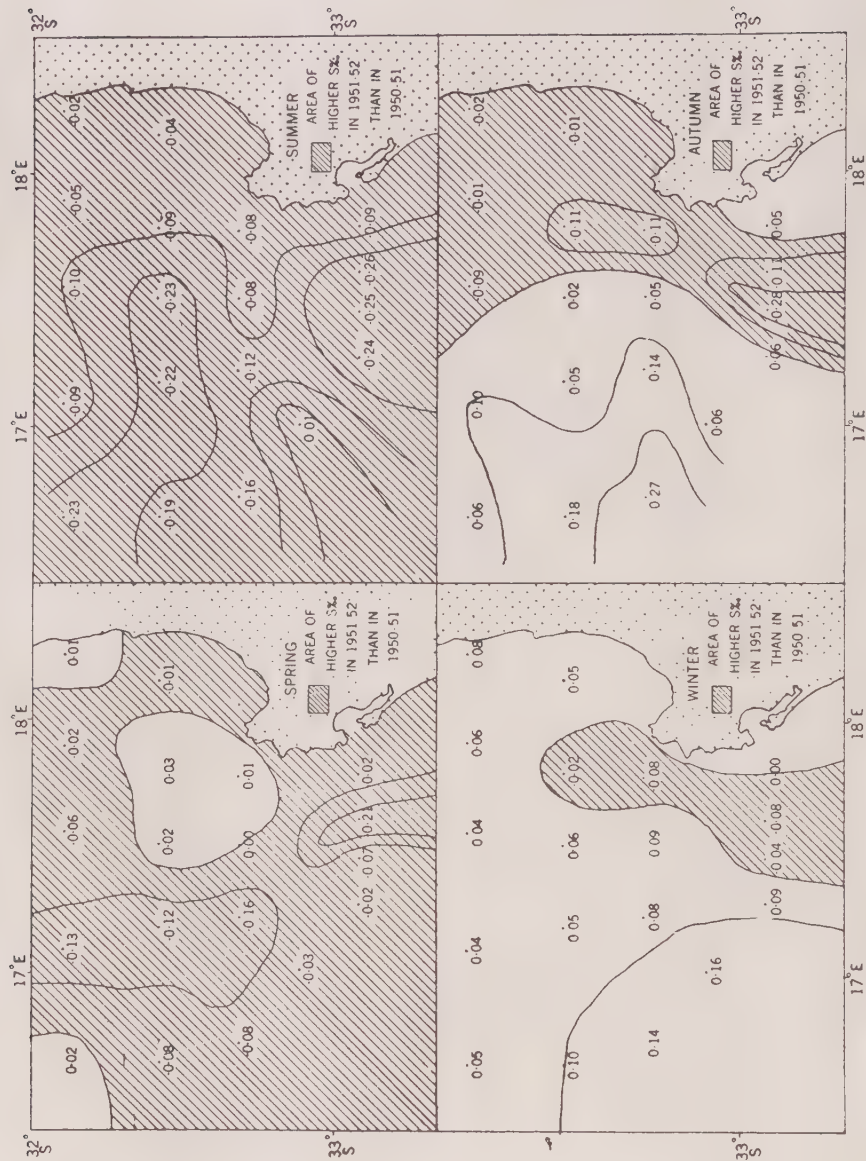
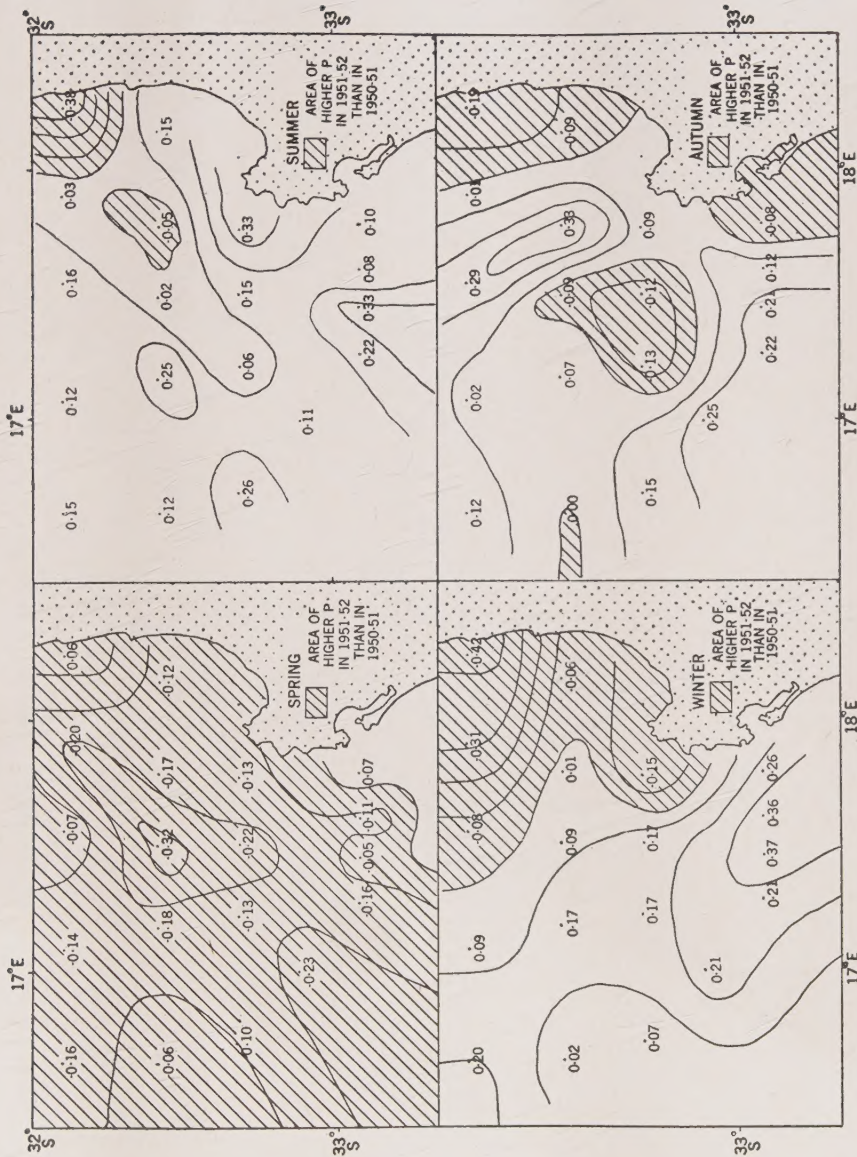


PLATE XV SEASONAL DIFFERENCE OF TEMPERATURE IN 0.05 METRE LAYER IN 1950-51 AND 1951-52



Tringsurvey, 1954
Government Printer, 1954
PLATE XVI SEASONAL DIFFERENCE OF SALINITY IN 0.50 METRE LAYER IN 1950-51 AND 1951-52



Trigsurvey 1954.

PLATE XVII SEASONAL DIFFERENCE OF INORGANIC PHOSPHATE IN 0-50 METRE LAYER IN 1950-51 AND 1951-52.

Government Printer, 1954.

